University of Southern Queensland

Faculty of Engineering and Surveying

Evaluation of Precise Point Positioning Services

A dissertation submitted by

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ABSTRACT

Precise Point Positioning (PPP) is a Global Navigation Satellite System (GNSS) positioning method which enables the calculation of a precise position utilising a single geodetic quality GNSS receiver and PPP software. There has been a range of research which has examined the accuracy and reliability of freely available online PPP services. This study will look to confirm the results of previous findings and follow up on some gaps identified in existing research.

This study compared the performance of AUSPOS, OPUS, CSRS-PPP and Magic PPP. It initially compared them to existing Survey Control Information Management System (SCIMS) coordinated survey marks but discovered the SCIMS coordinates were not suitable for comparison. It examined solutions for bias as well as comparing the differential baseline processing method to true PPP method. It examined the effect of including GLONASS satellite observation data with GPS satellite observation data in order to develop a solution and it compared the results to previous studies in order to test the reliability of research to date.

The results of this study confirmed the results of previous research and found that that all solutions were similar (ASPOS, OPUS and CSRS-PPP solutions are all in the order of ten millimetres apart). It confirmed that twenty-four-hour observations are the minimum required in order to derive a reliable height coordinate and that observations exceeding six hours provide minimal improvements in horizontal position. It identified a distinct bias of results between solutions and identified that reference station network and location may be a significant cause. The differential baseline processing method was more precise than true PPP and the GNSS derived solution whilst not significantly more or less accurate than the GPS solution, was more precise and the outliers were closer to the average solution.

LIMITATIONS OF USE

CANDIDATES CERTIFICATION

I certify that the ideas, designs and experimental work, results, analysis and conclusions set out in this dissertation are entirely my own efforts, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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(Date)

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NOMENCLATURE AND ACRONYMS

The following abbreviations have been used throughout the text and bibliography:-

AHD	Australian Height Datum
AHD71	Australian Height Datum 1971
APREF	Asia Pacific Reference Frame
CORS	Continually Operating Reference Station
ECEF	Earth Centred Earth Fixed
ESTR89	European Terrestrial Reference Frame 1989
FCN	Frequency Channel Number
GDA94	Geocentric Datum of Australia 1994
GLONASS	Globalnaya navigatsionnaya sputnikovaya sistema (Global Navigation Satellite System)
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
ICSM	Intergovernmental Committee on Surveying and Mapping
IGS	International GNSS Service
IGS08	International GNSS Service 2008
ITRF	International Terrestrial Reference Frame
ITRF2008	International Reference Frame 2008
LPI	Land and Property Information
NAD83	North American Datum 1983
PPP	Precise Point Positioning
RINEX	Receiver Independent Exchange Format
RTK	Real Time Kinematic Surveying
SCIMS	Survey Control Information Management System
SU	Survey Uncertainty

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CHAPTER 1 - INTRODUCTION

1.1 Background Information

The use of Global Navigation Satellite Systems (GNSS) products and services is now common place in human life. It is seen in navigation, machine guidance, surveying, network development, mapping and even in sports. Advances in technology have made GNSS products and services more affordable, more accessible and more accurate, increasing their use within society generally.

The surveying profession has embraced the technology, recognising the efficiencies it provides. Real Time Kinematic (RTK) surveying has been the preferred method used in cadastral and construction surveying. It comprises two GNSS satellite receivers, one a base station placed in a fixed position, the second a roving unit which is transported from place to place recording observations in the area being surveyed in real time. RTK relies upon the ability of the system to provide real time corrections to solutions at the roving unit.

Geodetic surveying practices have typically employed static GNSS observations utilising multiple base stations simultaneously. This enables the formation of a network of baselines from which to coordinate survey control marks. This has its own limitations and is relatively costly (Ebner & Featherstone, 2008). It requires the duplication of resources and is logistically challenging due to the need to move base stations around vast distances to enable simultaneous occupations and observations. The use of a static single GNSS dual frequency receiver (recording undifferentiated pseudo range and carrier phase observations and incorporating post processed data in order to compute accurate coordinate solutions) has been investigated in more recent times for its flexibility, reduced cost relative to multi station simultaneous occupations and the potential for acceptable levels of accuracy (Ebner & Featherstone, 2008). In real time applications however, the single receiver method is not practical as it requires long occupations to enable the float solution to converge in order to determine an accurate positional solution (Gao, 2009 cited in Grinter & Roberts, 2011).

In applications where a real time position is not a requirement, the single receiver static data is post processed in order to compute a solution. Whilst this means a delay or added step in the process of developing control, the use of a single receiver still offers a viable, cost effective alternative when establishing a coordinated network in places where few if any coordinated networks exist.

Precise Point Positioning (PPP) is essential in single receiver observations in order to correct for the various errors that are inherent in raw observation data. These errors are caused by such things as atmospheric composition, differences in satellite and receiver clock accuracies, differences in modelled and actual satellite position and orientation and geological effects. Fortunately post processing has been aided by the provision of freely available online processing services. These online services utilise either a traditional differential baseline processing method or true PPP to develop a solution (Tsikiri, 2008).

Differential baseline processing utilises the nearest continually operating reference stations (CORS) with known coordinates and forms baselines between those and the occupied mark. It does this by processing raw data from the receiver and generates the baselines formed by the network of stations and the point being surveyed to calculate corrected solutions. PPP post processing utilises a different method of processing the data. It uses the undifferenced carrier phase and code phase observations and requires accurate knowledge of satellite coordinates as well as the state of their clocks and earth rotation parameters in order to process a solution (Martin et al, 2010). Whilst both methods have differences at the modelling level and with data control algorithms, both employ the same fundamental mathematical principals (Tsakiri, 2008, pp 116).

Studies which have been undertaken to examine the performance of these online post processing services suggest that the solutions they generate for the same set of data are very similar (Silver, 2013) (Cleaver, 2013). However, gaps in existing research identify the need to examine repeatability, the impacts of additional GNSS constellations on a solution and bias between processing methods. Cleaver (2013) identified detectable differences between PPP and baseline solutions and suggested that this could be due to baseline bias. Whilst the potential for bias has been identified, further investigation will help to provide greater understanding of cause and effect. Given this information, it may be possible to provide guidance on what service might be suitable for a given scenario.

More studies are required in order to confirm the reliability and accuracy of the results obtained by the various methods of PPP. In addition there needs to be more focus on whether a bias impacts the final solution and to what extent. This study aims to confirm the results of previous research as well as to address the identified gaps. Solutions generated from identical data will be compared for bias between processing methods and raw Global Positioning System (GPS) observations will be compared with solutions where GPS and GLONASS observations are combined.

1.2 Research Aim and Objectives

The aim of the project is to evaluate and compare the performance of PPP and differential baseline methods of online post processing services, when processing the same data captured over extended periods of time and in multiple data collection sessions. This will be achieved by statistically analysing the accuracy and precision of processed solutions, comparing solutions from each method of post processing to identify the existence of any bias and comparing the processed solutions to the known coordinates.

The objectives of the study are to:

1. Establish background knowledge of relevant geodetic surveying practices, data collection methods, equipment and GNSS post processing services,
2. Research the differences between true PPP and differential GNSS post processing services,
3. Identify service providers and research methods of online post processing (eg Trimble's RTX, CSRS from Natural Resources Canada, Auspos from Geoscience Australia and OPUS, the United States Government run service from the National Geodetic Survey website.
4. Research Statistical Analysis,
5. Develop a method for data collection that will allow the necessary comparisons to be made,
6. Process data and statistically analyse results,

7. Evaluate results of data analysis to determine if any bias exists between the different methods of post processing,
8. Compare post-processed solutions to known coordinates to evaluate accuracy and precision of solutions for different logging times,
9. Compare solutions from GPS derived post processed data to that of solutions derived from GPS and GLONASS data in order to evaluate accuracy and precision, and
10. Examine repeatability of results by comparing solutions from data collected over multiple sessions and multiple days.

1.3 Justification

Previous studies have identified the role GNSS can play in geodetic surveying and in particular the development of survey control in areas where little if anything in the way of an established coordinated network exists. One of the significant challenges in this scenario is developing a coordinated network in a cost effective and efficient manner. Utilising static observation data and post processing services enables the development of a collection of control points with suitably accurate coordinates in an efficient and cost effective way.

These post processing services will quickly and easily produce output. However, users must be confident that the data they are producing is suitably accurate and precise for the intended use. A greater understanding of how these services produce a solution will enable more confidence to be placed in the output and will help users decide which service might be suitable for their particular application.

Whilst some studies have been undertaken to demonstrate the resulting accuracies from different post processing service providers, these studies are not extensive. They have typically utilised data from a single point to compare processing services, or utilised data from single sessions at multiple points. Where multiple points have been sampled, data has been observed at each point on different days. This introduces uncertainty with varying environmental factors experienced and different sets of satellites being observed for each session. Therefore the errors in observations will vary slightly from one day to the next. There is limited research which has examined the results of processed data captured over multiple days, at multiple sites and processed by multiple services in order to compare results and examine reliability and repeatability. In addition to this, the introduction of GLONASS satellite data and other GNSS constellations into post processing services requires research in order to ascertain what if any effect these have on a final processed solution.

Therefore, there is a need to process data collected over multiple days and sessions from multiple sites in order to better examine reliability and repeatability of the method and thus augment the results of previous studies. Observations taken at all sites at the same time will enable the isolation of the effects of some errors. There is also a need to compare processing methods for the existence of any bias, as this has been identified but not extensively examined in research to date. This will enable the effects of bias to be considered in the context of the project being undertaken and a decision made on the suitability of one service or processing method over another.

1.4 Summary

This chapter has provided an overview of how PPP has been incorporated into modern geodetic surveying practices and the requirements that exist in incorporating PPP as a reliable and effective solution to a particular surveying problem. It also demonstrates a need to further examine the reliability, repeatability and accuracy of post processing services to provide greater confidence in the process. The following chapter will review the literature surrounding the technology in order to provide a base knowledge from which to design and carry out the necessary experiments and interpret the findings.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction.

To progress this research it is necessary to examine background information on geodetic surveying and the equipment and systems used in determining accurate and precise three dimensional point coordinates. An examination of research to date in the field of post processing details the gaps in this research which have been identified in Chapter 1.

The aim of this chapter is to gain sufficient understanding of geodetic surveying and post processing techniques. This will enable the planning and preparation of a suitable project method to examine precise point positioning and critically and statistically analyse results in order to draw appropriate conclusions and recommendations.

This will be done by identifying suitable equipment and survey sites as well as researching freely available, online post processing services that would be suitable for post processing raw GNSS observation data. It will also examine the research to date, identifying what gaps, limitations or shortfalls exist and how these will be addressed in this study.

2.2 Geodetic Surveying

Geodesy is the science of measuring the Earth's size and shape including objects thereon, as well as determining the gravitational field and other forces and anomalies. Geodetic surveying is the physical process of taking measurements of the Earth's surface taking into consideration size, shape, curvature, time, gravity and other forces and anomalies. Geodetic surveying is undertaken to locate features on the Earth's surface relative to their position in latitude, longitude and ellipsoidal height. Modern geodetic surveying utilises GNSS receiver equipment and signals from GNSS constellations in order to calculate a position solution. This information can be used to convert the solution to a suitable local coordinate system and datum. Post processing services provide a bridge to take GNSS-derived raw observation data and compute corrected 3 dimensional coordinates. These are typically provided in the form of International Terrestrial Reference Frame (ITRF) coordinates although some services offer additional options relevant to their area of origin. For example, AUSPOS provides solutions in ITRF2008 and Geocentric Datum of Australia 1994 (GDA94).

2.3 Equipment

The Equipment used in geodetic surveying is typically high precision geodetic quality equipment and associated computer hardware and software. Specifically, this includes GNSS dual frequency receivers, high precision total stations and prisms, differential levelling equipment, including automatic level and staff, and a computer, dedicated software and/or calculator to process the data.

Modern geodetic surveying is typically undertaken with GNSS equipment due to the efficiency of operation. In order to do this however, there is a requirement for an underlying coordinated network from which to base the survey. Modern geodetic surveying also relies upon a worldwide network of CORS as well as the multiple GNSS constellations orbiting the earth.

2.3.1 GNSS Receivers

GNSS receiver systems are comprised of a satellite receiver and antenna (some equipment comprises both together), a data storage device such as a SD card, expandable storage option or internal memory system, tribrach, tripod and batteries. This equipment functions by logging raw observation data from constellations of satellites orbiting the earth. These satellites emit a signal in the form of radio waves that are detected at the receiver. The distance to each satellite is then calculated from the time taken for the signal to reach the receiver. A minimum of four satellites must be visible to the receiver in order to calculate a position. This data can be post processed in order to counter the effects of various errors and determine a corrected solution

2.4 On Line Post-Processing

Post-processing services are freely available on line by various providers. These services take raw unprocessed GNSS observations and calculate a solution factoring in various error corrections. Each uses its own variation of processing software and as stated previously, differential baseline processing or PPP is employed (Tsikiri, 2008).

The raw data observed at the receiver are pseudo range and carrier phase measurements. The pseudo range is the distance between the satellite sending the signal and the receiver. It is determined by multiplying the difference between the time the signal was transmitted from the satellite and the time it was received at the receiver, by the speed of light. Due to clock synchronisation differences between satellite and receiver this measurement includes a clock error. The carrier phase measurement is the difference between the phase of the carrier signal generated by the satellite and a duplicate signal generated by the receiver. It is a fractional component as the actual phase cycles are unknown. It is referred to as the integer ambiguity and it remains unknown until the data is processed (Crawford, 2013).

2.4.1 Precise Point Positioning

For geodetic quality surveys, a dual frequency receiver is used. When observation data from these receivers is combined with GPS and other GNSS orbit and clock correction products, an accurate solution can be derived. In forming a solution, the effects and corrections which must also be factored in include; receiver clock errors, phase wind-up corrections, satellite antenna phase centre corrections, solid earth tide corrections, polar motion, neutral atmosphere delay, ionospheric delay and ocean loading corrections (Grinter & Roberts, 2011) (Alison et al n.d.). This method can provide a positioning solution in a dynamic, global reference frame such as the ITRF (Grinter & Roberts, 2011).

2.4.2 Differential Baselines – Differential GNSS (DGNSS).

This method requires observations to one or more base receivers at reference stations with known coordinates (in addition to the receiver recording observation data at the surveyed point). This data is then processed by differencing pseudo-range or carrier phase observables for all stations. (Grinter et al, 2012). This can be single, double or triple differencing.

Single differencing is where observations are recorded from a single satellite by two receivers simultaneously. This method eliminates satellite clock and orbit errors and reduces atmospheric errors in short baselines. Double differencing is where observations are recorded from two different satellites by two receivers simultaneously.

A single difference is then undertaken for each satellite before the difference between the two single differences is taken. Double differencing eliminates satellite and receiver clock error, and reduces or eliminates orbital errors and atmospheric effects. Triple differencing takes the difference between two double differences separated by a time interval and cancels phase ambiguity bias (Crawford, 2013 p27).

In real time applications, such as RTK surveying, the base station is receiving the same signals as the remote receiver and any errors experienced at the base receiver/s are therefore also being experienced at the remote receiver. This means that the differences between the observed solution and calculated solution at the base station/s can be applied to the solution at the remote receiver in order to determine a corrected solution. (University of Southern Queensland, 2009, pp. 109-112). Where real time corrections are not required or are unable to be applied, the raw data can be post processed and the corrections applied to each point surveyed. In a single receiver survey, CORS can be used to generate the baselines required to calculate solutions.

2.4.3 Online Post Processing Services

When online post processing is proposed, an appropriate service must be identified and chosen to perform the necessary corrections and calculation of position. By researching other studies and conducting online searches, a number of available service providers were identified and are listed in Table 2.1.

Silver (2014) identified and compared these eight potential service providers (see Table 2.1) and found that with the exception of one (SCOUT was excluded due to hardware incompatibility), processing identical data with each service resulted in very similar solutions. When comparing the solution from OPUS to the remaining six services, the differences were generally within 5mm in Easting, Northing and ellipsoidal height. Silver (2014) suggests that the similarity of solutions demonstrates the robustness of the algorithms and processes they use.

Table 2.1 Publicly Available Online Post Processing Services

Service	Provider	GNSS Types	Processing Method
AUSPOS	Geoscience Australia	GPS	Differential Baseline utilising 15 nearest IGS and APREF reference stations.
OPUS – Online Positioning User Service	National Geodetic Service – USA	GPS	Differential Baseline utilising 3 nearest CORS
CSRS_PPP – Canadian Spatial Reference System	Natural Resources Canada	GPS & GLONASS	PPP
GAPS – GPS Analysis and Positioning Software	University of New Brunswick Canada	GPS	PPP
APPS – Automatic Precise Positioning Service	NASA's Jet Propulsion Laboratory California Institute of Technology	GPS	PPP
SCOUT – Scripps Coordinate Update Tool	Scripps Orbit and Permanent Array Centre, University of California San Diego	GPS	Differential Baseline utilising the three nearest CORS
magicGNSS	GMV	GPS & GLONASS	PPP
CenterPoint RTX	Trimble Navigation	GPS, GLONASS, QZSS, Galileo & BeiDou	PPP

2.6 Previous Research

There has been some research on the reliability and accuracy of post processing services. An overview of some of the more relevant studies is provided below.

2.6.1 Cleaver

Cleaver (2013) compared different online post processing services, including AUSPOS, SCOUT, CSRS-PPP and GIPSY. The GPS observation data from each of four surveyed locations was processed by each service and the results analysed and compared for precision. Solutions were also examined for positional accuracy by comparing them to known survey control coordinates. Cleaver found that the differences between three of the services were a fraction of the magnitude of the residual differences of known survey control. He found that differences between average residuals obtained from each service by processing identical data was in the order of 20mm for easting, 7mm for northing and 20mm for height with 24 observations and that trends in consistency of the processed coordinates indicated that baseline services were marginally more accurate than PPP services. He found that coordinate accuracy when compared to a known point was in the magnitude of 2-3cm horizontally and 100-150mm in height. In addition he found that there were minor but detectable differences between baseline solutions and PPP solutions.

The data from this study was limited to a single session for each particular survey control mark and recommended additional occupations on different days and times to examine repeatability. Cleaver also suggested incorporating data from other GNSS providers in the processed solution. Therefore, this study will undertake multiple days of observations at each survey mark and will compare GPS based solutions to GNSS solutions to examine accuracy and precision.

2.6.2 Silver

Silver (2014) set out to compare data processed by each of eight different post processing service providers as set out in Table 2.1. SCOUT was ultimately discounted in this study as the GNSS equipment used was not compatible with the processing software. Silver's aim was to shed some light on other processing options available to the profession with the impending shutdown of the US Government Service, OPUS

(OPUS has since resumed operation). Data collected from a single point over thirty-two consecutive days was broken into twenty-four one hour sessions per day and each of the thirty-two days of data processed using each of the post processing services. Silver compared the average result of each method to that produced by OPUS and found that all results were very similar. He found that the differences in X, Y and elevation were typically within 5mm. He concluded that the results demonstrated a robustness of the algorithms and processes used. Silver suggests that AUSPOS, RTX, GAPS, OPUS and CSRS-PPP would be suitable for important positioning projects. His study, however, is US focussed and therefore may not hold true for other regions.

Silver made comparisons of the averaged processed solutions from a single point from each of the service providers over thirty-two consecutive days and the data was limited to GPS observations. In this study a similar comparison of solutions will be made with four different service providers but observation data files will be processed in three-hour packets. This will be done to accommodate the limitations in file size processing by one of the service providers and gives better opportunity to resolve for ambiguity.

2.6.3 Tsakiri

Tsakiri, (2008) compared the results of processing identical data with four globally available online GPS processing services for the purposes of datum realisation. Tsakiri found that twenty-four hour data sets were repeatable to the 1-2cm level and accurate to the 3-4cm level but solutions deteriorate as processing time reduces. At six hours, repeatability rose to 2-4cm and accuracy 3-7cm. Tsakiri found that whilst the different post processing services use software derived from similar mathematical algorithms and models, the results vary. None of the service providers were regulated to a standard and as such results could not be guaranteed. Expert knowledge in GPS data analysis is required to interpret the reports provided by the services to ensure quality control. Therefore it is only through continued and repeatable research that any confidence can be placed in the outputs from these services.

2.6.4 Cai & Gao

Cai & Gao (2012) presented an observation model for the Russian Globalnaya navigatsionnaya sputnikovaya sistema (GLONASS) PPP addressing hardware delay bias and providing an algorithm to compute frequency channel number (FCN) in order to remove the need to provide GLONASS FCN during data processing. Relevant to this study however, is that they also compared observation residuals from GLONASS based PPP to that of GPS based PPP for the same reference stations. GLONASS based PPP achieved positional accuracy of 35mm, 54mm and 86mm in the north, east and up directions whilst GPS based PPP achieved an accuracy of 15mm, 31mm and 77mm. The lower average availability of GLONASS satellites was critical in explaining the difference. This study will examine the effects of combining GPS and GLONASS data to form a solution and compare this to GPS only based solutions.

2.6 Summary

This chapter has detailed the post processing service providers available to users. It has identified the equipment required in order to conduct geodetic surveying projects. It has examined the existing research in post processing services and identified opportunities for further research. This has highlighted the need to occupy multiple points over multiple days to test repeatability, compare PPP and differential baseline processing methods for the impacts of any bias, compare calculated solutions to known coordinates and compare GPS and GPS + GLONASS (referred to as GNSS) observations, to assess accuracy and precision.

In chapter three, the method will be explained and testing regime set out in order to address the gaps in research identified above. The aim of this will be to provide sufficient information from which to draw relevant conclusions.

CHAPTER 3 - METHOD

3.1 Introduction

This chapter aims to examine the considerations which influenced the design of the experiments and processes followed. It details the testing method adopted, the survey sites chosen, the equipment utilised and the processing services employed.

The research required the comparison of solutions from various online post-processing services in order to evaluate their performance. To this end, static survey data was required to process solutions. Therefore, single GNSS receivers were used to record static satellite observation data over survey marks with known geodetic quality coordinates. This data was then submitted to the various online post processing services and the processed solutions compared.

This chapter will enable the reader to understand how the project was developed and what testing procedures were used. It will also provide the reader with an understanding of how the method will enable the gathering of suitable and sufficient data in order to evaluate the performance of the various service providers and satisfy the aims and objectives of the study.

3.2 Project Constraints

There are several considerations in the development of a suitable experimental design for the study. These considerations governed the survey marks selected for testing, the field and office equipment used and the testing regimen followed.

The requirements for comparing results to known coordinates meant that marks with the highest possible quality of position were preferred so that they could be used to compare to the derived solutions for accuracy. The New South Wales Government Land & Property Information (LPI) specifies that marks of Class A and above are geodetic survey quality and as such this was the minimum standard acceptable when choosing suitable marks.

Given the need for prolonged occupations and clear vision to the sky, the sites needed to be clear of obstructions, free from potential causes of multipath and be safe for leaving equipment unattended for long periods of time. This enabled the best possible chance of collecting clean data and thus the most accurate data from which to develop the most accurate and precise solutions. In addition to these considerations, the marks needed to be in close proximity to one another to permit driving between sites in reasonable time. This requirement was due to the desire to carry out observations concurrently and ensure the logistical challenges of operating on separate sites at the same time could be met.

Equipment availability was restricted to that which was accessible from my employer. Also in consideration was the limited availability of geodetic quality marks which were deemed suitable for use given the above constraints. Therefore, the number of sites being surveyed was limited to the two trig stations. The two Trigonometric (Trig) stations chosen were thirty-three kilometres apart and could be travelled between within an hour meaning they satisfied the given constraints.

3.2.1 Equipment

Two Leica Viva GNSS GS14 receivers utilising SmartWorx Viva 5.02 firmware were made available by my employer for use during the data collection sessions of the experiment. These were placed on site at the two trig stations. Also required at these stations were tribrachs for mounting the receivers to the stations and a portable electric fence to secure the immediate area around the station from livestock. Software included Leica Geo Office which was used to manage the raw data from the receivers and convert it into Receiver Independent Exchange (RINEX) format.

3.2.2 Field Method

The Intergovernmental Committee on Surveying and Mapping (ICSM) in their Guideline for Control Surveys by GNSS (2013) specifies that an observation epoch interval of thirty seconds is the minimum recommended in order to achieve a nominal level of survey uncertainty (SU). For horizontal position this is SU<15mm and SU<20mm for ellipsoidal height. The observation length recommended for horizontal position is provided in a range of between six and twenty-four hours but for height is stated as being a minimum of twenty four-hours. Cleaver (2013) found that observations in excess of 4 hours did not improve the accuracy of the processed solution. Ebner and Featherstone (2008) found that observations in excess of two days were required in order to achieve reliable results. However, a continuous observation for as long as possible was recommended. Martin et al (2010) reflected that of the ICSM recommendation and suggested a minimum of twelve hours is required for horizontal coordinates but twenty-four hours is essential for height. This demonstrates some conflicting recommendations in existing research and as such this study aims to resolve these inconsistencies.

Occupations for each site in this study were for a twenty-four-hour time period at an observation epoch interval of fifteen seconds. This is intended to maintain consistency with some of the studies identified. This will provide sufficient data for processing, comparison and assessment.

The occupations were undertaken on three separate dates for each site to test repeatability. Observations at each of the sites were intended to be undertaken simultaneously to provide the best opportunity to isolate the effects of error. Due to equipment failure Session A of the testing at each site was undertaken several days apart. Whilst not ideal, non-simultaneous occupations are not inconsistent with other studies in this field. Previous research has not highlighted any identifiable errors attributable to conducting surveys on different days and therefore should not introduce any major cause for difference between data sets. Session B and C however, were undertaken simultaneously.

3.2.3 Survey Sites

The survey sites were chosen to provide the best possible quality of signal as well as meeting the requirements for accessibility, proximity, mark quality and accuracy. The trig stations chosen are part of the New South Wales Government's LPI coordinated network and are identified below.

Hayter Trig Station - TS7270HAYTER

GDA94 - Class A – National and State Geodetic Survey

Coordinates as at 8 July 2014

MGA56	Easting:	558577.506
	Northing:	6827642.317

AHD71 - Class B – Trigonometric or GPS heighting for cadastral control (standard deviations of observations <15(d + 0.2)mm)

AHD71	RL 116.698

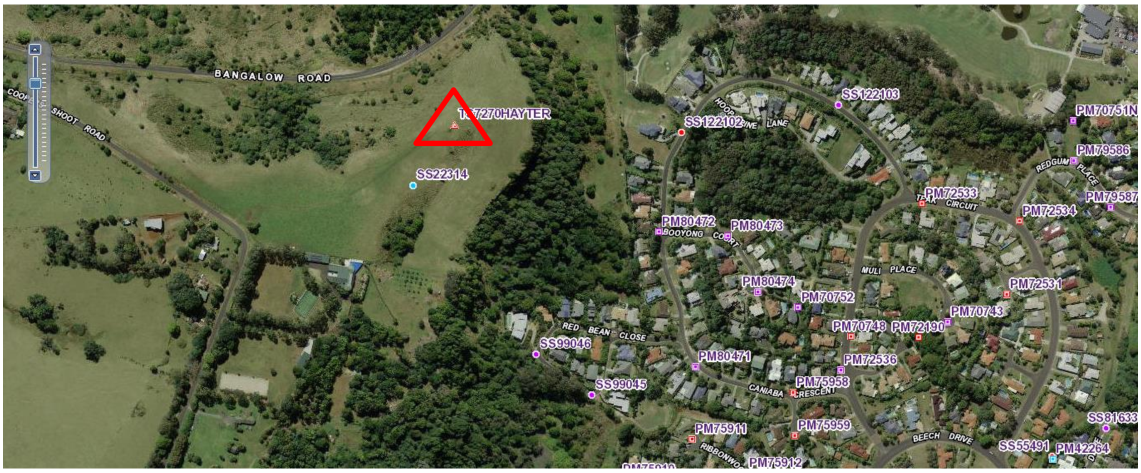

Figure 3.1 Aerial Photo of Hayter Trig Station at Coopers Shoot (Spatial Information Exchange, 2014)

Figure 3.2 Site Photo of Hayter Trig Station

Meerschaum Trig Station - TS6600MEERSCHAUM

GDA94 - Class 2A – High precision National Geodetic Survey

Published coordinates as at 8 July 2014

MGA56	Easting:	541326.531
	Northing:	6799204.769

AHD71 - Class LA – First order levelling (forward and backrun misclose <4√d)

AHD71	RL 170.558

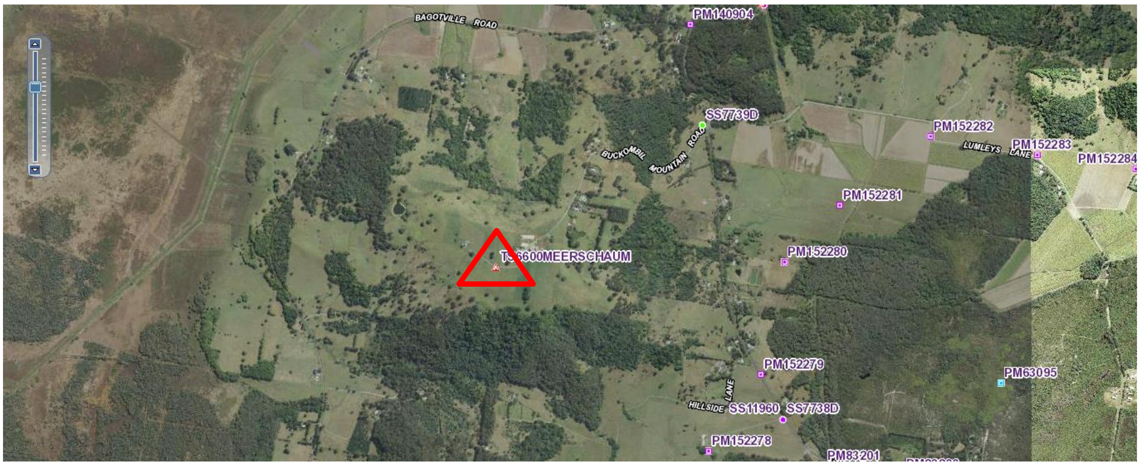

Figure 3.3 Aerial Photo of Meerschaum Trig Station, Meerschaum Vale (Spatial Information Exchange, 2014)

Figure 3.4 Site Photo of Meerschaum Trig Station

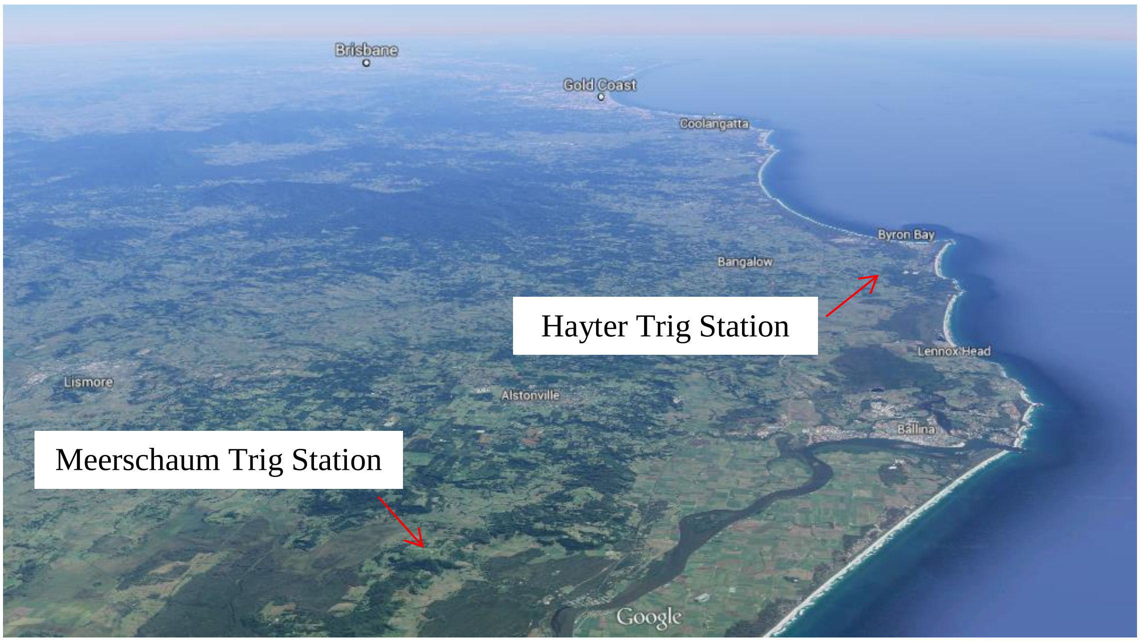

Figure 3.5 Aerial Photo of North East NSW (Google Maps, 2014)

Figure 3.5 gives an overhead photo of the north east coast of NSW and identifies the location of the two trig stations. This enables an appreciation of the proximity of the marks to one another and their location with respect to the region.

3.3 Data Processing

3.3.1 Raw data

The Leica GS14 receivers were set up to log raw data in Leica format. Each of the processing systems requires that submitted files be in a particular format. All providers were RINEX compatible and as such the data files derived from the GS14 receivers were converted in Leica Geo office before being edited and submitted to the various post processing services. Upon conversion to RINEX, each of the observations files was decimated into one-hour, two-hour, three-hour, four-hour, six-hour, eight-hour, twelve-hour and twenty-four-hour observation files before submission to the respective online data processors.

3.3.2 Processed data

In order to satisfy the objectives of the research, two differential baseline type processing systems were compared with two true PPP processing systems. Given Silver's findings and taking into consideration the service providers employed in similar research to date and equipment compatibility, a short list of suitable providers was chosen. These are listed below

3.3.3 AUSPOS

AUSPOS is a Government run service under the auspices of Geoscience Australia. It is a free online post processing service utilising Bernese GNSS Software and processing GPS data only. The Bernese system is a high precision orbit and geodetic parameter determination software system. It utilises the raw data in RINEX format and the 15 nearest International GNSS Service (IGS) & Asia Pacific Reference Frame (APREF) stations for reference stations and employs the double difference technique to determine a precise solution. Figure 3.6 shows a world-wide plot of the IGS reference stations. Whilst figure 3.7 shows a plot of reference stations in the Australian Region of the APREF

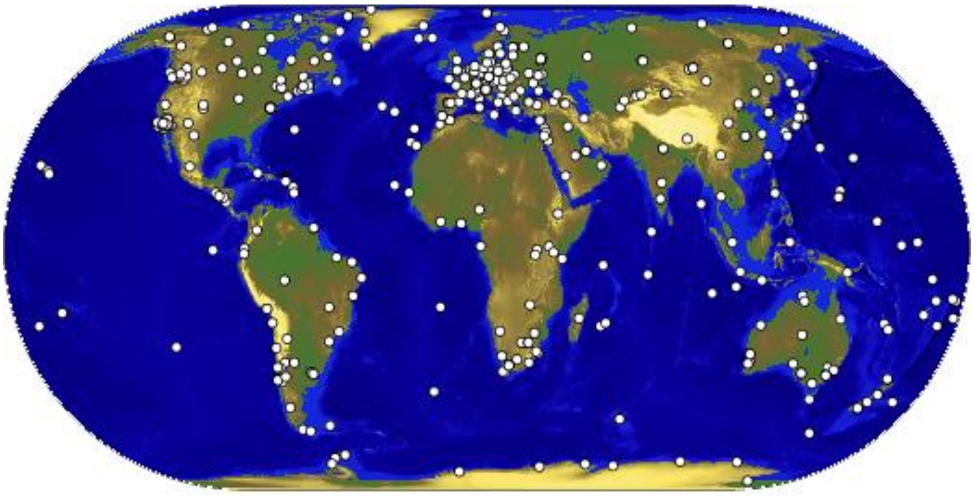

Figure 3.6 IGS Tracking Network (International GNSS Service, 2014)

Figure 3.7 APREF Network of CORS in the Australian Region (Geoscience Australia, 2014)

Error modelling and estimations are used to counter the effects of observation errors such as those caused by the troposphere and ionosphere and receiver clock errors. The coordinates are presented in the International Terrestrial Reference Frame 2008 (ITRF2008) and GDA94 format (for Australian users). Due to the global coverage of the IGS network, the system can be utilised in any part of the world.

This system was chosen as it is recommended by the ICSM and has been developed in Australia for Australian users. It has also been examined in similar research by Cleaver (2013), Koschel (2012) and Silver (2014).

3.3.4 OPUS

OPUS is controlled by the US Government and is maintained by the National Geodetic Service. It processes GPS only data and coordinates are averaged from three independent, single-baseline solutions, each computed by double-differenced, carrier-phase measurements from one of three nearby CORS. Although the CORS are primarily located in the North American Continent and Europe, OPUS employed local CORS for the data processed in this project. OPUS was chosen due to the requirement for a second differential baseline processing system and because the survey equipment used was compatible. It provides solutions in IGS08 which is 'an extraction from ITRF2008 to which position corrections are applied for the receiver antenna calibration update' (Collilieux et al, 2012 p 484).

3.3.5 Magic GNSS

Magic GNSS is provided by GMV, a privately owned technological business group. It incorporates a number of product options including MagicPPP. This utilises an in-house developed PPP algorithm which processes dual-frequency code and phase measurements in the form of RINEX observation data from GPS, GLONASS and Galileo constellations. It employs a proprietary precise orbit determination and time synchronization suite to generate the core products of the system and these are automatically generated by processing data from a network of around 100 worldwide distributed stations (GMV, 2014). It produces solutions in the European Terrestrial Reference System 1989 (ETSR89) and ITRF2008.

3.3.6 Canadian Spatial Reference System PPP (CSRS-PPP)

CSRS-PPP is a Canadian Government run service under the umbrella of Natural Resources Canada. It is a true PPP system, utilising precise GNSS satellite orbit ephemerides to produce corrected coordinates of a constant "absolute" accuracy. It utilises both GPS and GLONASS observation data to process a solution. At the heart of the system is the Canadian Active Control System comprising a network of continually operating GNSS receivers. It processes single or dual frequency receiver RINEX observation data which can be from static or kinematic observations and produces solutions in North American Datum 1983 (NAD83) and ITRF2008.

3.5 Data Comparisons

In order to analyse and assess the performance of the services, a variety of comparisons and statistical analyses were made of the results. The aim of which was to provide greater confidence on the use of post processing services.

Raw data observations were made on three separate days at each site in order to examine whether or not the results could be repeated with similar accuracy and precision. Each of the dissected file solutions from the post processors were compared in order to examine the accuracy and precision of solutions based on observation times that could be expected for any given survey. In particular, the twenty-four-hour observation files were processed with each service to compare best case accuracy and precision of calculated coordinates with that of the known coordinates.

GPS observation solutions were compared with GNSS observation solutions (where service providers were GLONASS compatible). This enabled the examination of the potential effects of the inclusion of GLONASS on the accuracy and precision of the solutions.

The processed solutions from the PPP services were compared with those from the differential baseline solutions to compare accuracy and precision as well as to examine whether or not any bias could be detected.

3.5 Summary

This chapter has presented the reader with an outline of how the method was developed and therefore how the resulting data will enable comparison of post processing services. The following chapter will examine the results of the experiment and provide the data necessary to evaluate performance and develop conclusions.

CHAPTER 4 – RESULTS

4.1 Introduction

In this chapter, solutions from each of the post processing services are presented in order to undertake the various comparisons outlined in the aims and objectives.

Results of processing the 24hr observations will be presented as the best case solutions and thus create a baseline of data from which to compare all other variations of solution. Solutions will also be presented based on varying observation lengths and then solutions will be presented based on data type, GPS vs GNSS. These results will form the basis from which comparisons and statistical analyses will be conducted in Chapter 5.

At the conclusion of this chapter, the reader should have an appreciation of how similar the results were, how there is some evidence of bias in the solutions and how different the solutions are to the SCIMS network in the region.

4.2 Processed Solutions

AUSPOS, being an Australian based service, provides GDA94 as well as ITRF2008 coordinates. All other services supply coordinates in their respective regional coordinate systems but also provide coordinates in ITRF2008 or IGS08. In order to compare the processed solutions with those provided by SCIMS, a transformation was required to convert the SCIMS GDA94 coordinates into ITRF2008. Each GDA94 coordinate was transformed using the Transxyz program. The transformation parameters were sourced from the AUSPOS solutions (an example of which can be found in Appendix G). These were tested to ensure the parameters were correct. The AUSPOS solutions were transformed from GDA94 to ITRF2008 to ensure the same solution was calculated manually as was provided by AUSPOS.

The test comprised the following steps in order to confirm the reliability of the transformation. Geodetic coordinates were converted to Earth Centred Earth Fixed (ECEF) coordinates utilising the Transxyz program. A fourteen parameter transformation was undertaken utilising the parameters sourced from AUSPOS to transform the coordinates to the current epoch at the time of each survey session. These were then converted to geodetic coordinates. The geodetic coordinates were then converted from geodetic coordinates to MGA56 utilising the Redfearn program. In order to carry out this transformation, a height conversion was required to convert the Australian Height Datum 1971 (AHD71) heights provided by SCIMS to ellipsoidal heights. As the separation was unknown in this region, the separation provided by AUSPOS was used (38.24 at Hayter Trig and 37.381 at Meerschaum Trig).

The expectation prior to undertaking the calculations was that the transformed coordinates would be very similar to the solutions derived from the various service providers, an assumption based on the results of previous studies. However, the results were significantly different to those derived from the various services. A distinct separation between the transformed coordinates and the solutions at each trig station was observed. This ranged from 0.067 – 0.091 m at Hayter Trig and 0.153 – 0.172 m at Meerschaum Trig. A separation of such magnitude brought into question the accuracy of the transformation process or the SCIMS coordinates. The transformation test above confirmed the manual calculation was able to be replicated correctly and accurately (utilising the AUSPOS provided parameters). Solutions from the other service providers were then used in order to undertake transformations from ITRF2008 coordinates to GDA94 coordinates. A similar separation of these solutions was observed in GDA94 as was seen in ITRF2008. As such, the suitability of the SCIMS coordinates for use as a truth from which to compare the solutions is questionable. Therefore an average of all the calculated solutions for each trig station was used in order to create a “truth” from which to compare all solutions. This “truth” became the origin for all calculations and thus all subsequent comparisons and analysis of accuracy were made utilising this “truth”. By doing this, the accuracy of solutions is no longer being tested against the SCIMS MGA network.

The origin was calculated from the average of all of the twenty-four hour observation solutions and is presented in the coordinate plots below. Various radius circles were also included from the origin in order to include a scale. These included five millimetre, ten millimetre and fifteen millimetre radius circles to give the reader a sense of the magnitude of the differences between solutions. All heights are presented as ellipsoidal heights and comparisons made to the average solution (origin).

The calculated origin at Hayter Trig Station was found to be 287°18’42” for 0.081m from the average SCIMS coordinate transformed to ITRF2008 using the AUSPOS parameters (see Figure 4.2). The transformed Meerschaum Trig coordinate was found to have an even greater separation from the calculated origin with the origin being 295°39’12” for 0.169m from the average transformed coordinate (see Figure 4.4). Further investigation with LPI uncovered that the separation of the coordinates and solutions is due to the fact that AUSPOS, OPUS, CSRS and Magic all provide solutions based on the ITRF2008, independent of local control networks. SCIMS coordinates are fitted to existing control with a least squares adjustment. Baxter (2014) reported that differences between SCIMS and solutions derived from AUSPOS or CORS can typically be 0.04 m or even larger. This is due to the original GDA94 adjustment and subsequent adjustments when coordinating survey marks throughout the state. He indicates that these errors have been propagated though the network and are likely to be more pronounced in rural areas due to the greater distances. The results of this study would confirm this view and indicate that in the North Coast Region of NSW there is a substantial difference between the SCIMS coordinates and ITRF2008. As such, any solutions derived from these online service providers would require connection to the existing network if network relevance was a requirement of a particular survey.

4.2 Twenty-Four-Hour Observation Solutions

The following information presents the processed solutions for the twenty-four hour observation files for each of the service providers at each of the survey sites.

4.2.1 Hayter Trig Station 24hr Observation Solutions

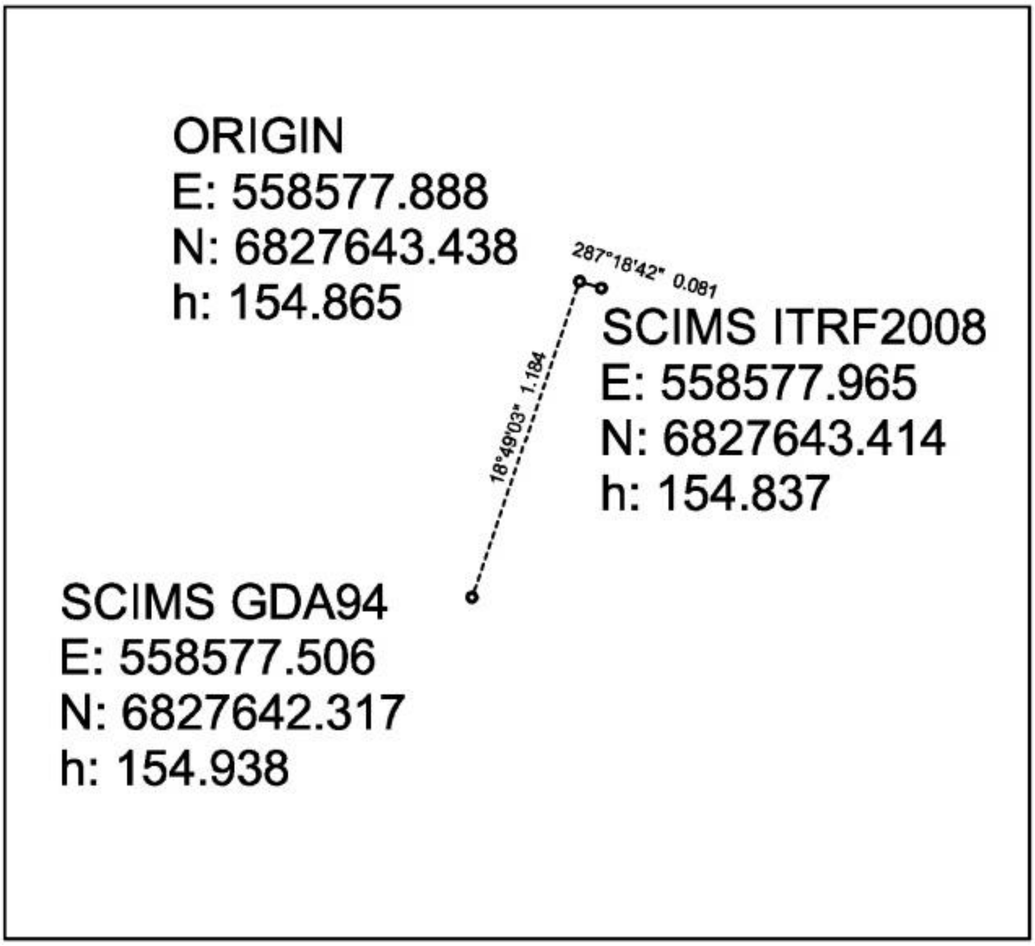

Figure 4.1 Plot of Comparison of SCIMS Coordinates, SCIMS Coordinates Transformed to ITRF2008 and the Average of the Processed Solutions (Origin) at Hayter Trig Station

Figure 4.1 shows the separation between the SCIMS GDA94 coordinates, the SCIMS coordinates transformed to ITRF2008 and the average of the twenty-four hour solutions (Origin) derived from the various service providers at Hayter Trig Station.

Tables 4.1, 4.2, 4.3, and 4.4 include the twenty-four-hour observation solutions from each service provider for each of the three survey dates (A, B & C) at each Trig Station. Figure, 4.2 is a plot of these solutions with the average of the solutions used as an origin from which to make comparisons.

Table 4.1 AUSPOS 24hr Observation Solutions – Hayter Trig

AUSPOS			
24hr A	558577.885	6827643.440	154.866
24hr B	558577.886	6827643.441	154.854
24hr C	558577.887	6827643.440	154.871
Avg 24hr	**558577.886**	**6827643.440**	**154.864**

Table 4.2 OPUS 24hr Observation Solutions – Hayter Trig

OPUS			
24hr A	558577.884	6827643.433	154.868
24hr B	558577.886	6827643.436	154.860
24hr C	558577.882	6827643.438	154.875
Avg 24hr	**558577.884**	**6827643.436**	**154.868**

Table 4.3 CSRS 24hr Observation Solutions – Hayter Trig

CSRS			
24hr A	558577.880	6827643.435	154.861
24hr B	558577.883	6827643.438	154.864
24hr C	558577.886	6827643.442	154.864
Avg 24hr	**558577.883**	**6827643.438**	**154.863**

Table 4.4 Magic 24hr Observation Solutions – Hayter Trig

Magic			
24hr A	558577.891	6827643.435	154.869
24hr B	558577.899	6827643.438	154.862
24hr C	558577.901	6827643.435	154.865
Avg 24hr	**558577.897**	**6827643.436**	**154.865**

The solutions extracted from each service provider are very similar. Easting coordinates are within 21mm, northing coordinates are within 9mm and heights are within 21mm. However, what is evident in the plot of coordinates in Figure 4.2 is that, the Magic solutions are biased towards the east and are substantially different to the solutions of the other three providers. Also evident is the AUSPOS solutions biased to the north and OPUS solutions to the south. It also appears that the CSRS solutions have a slight bias to the west. Whilst the solutions at Meerschaum Trig Station (see Figure 4.4) are reflective of those at Hayter Trig Station, the CSRS results are not consistent and the bias to the west is not evident there.

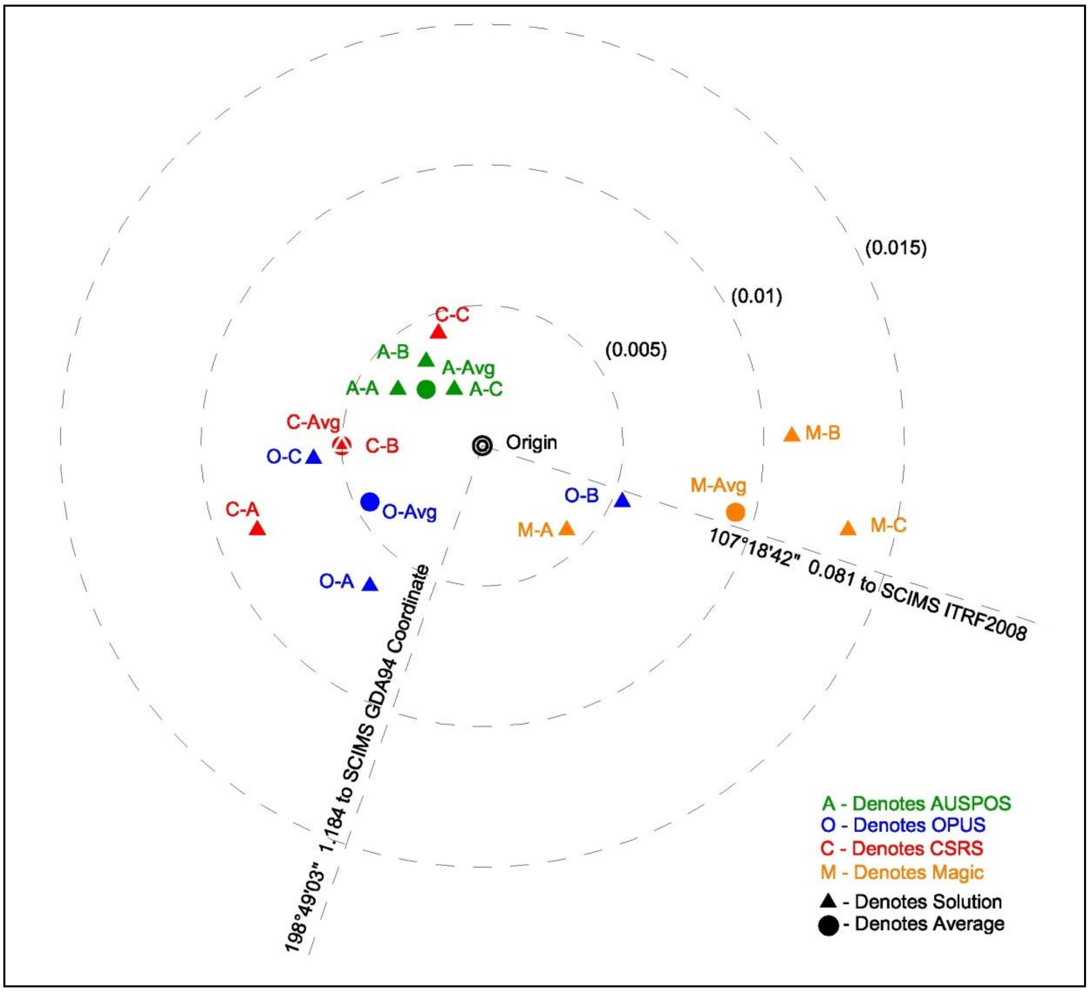

Figure 4.2 Plot of 24-hr Solutions - Hayter Trig

In Figures 4.2 and 4.4 each colour represents solutions from a specific service provider. The prefix identifies the service provider and the suffix represents the survey session from which the solution originated (either session A, session B or session C). Where a suffix is 'Avg' this is an average of the solutions from a particular service provider. The Origin is an average of all the twenty-four hour solutions and the rings around the origin are included as a scale. Each ring represents a 5mm increase in radius as you move away from the origin.

4.2.2 Meerschaum Trig Station 24hr Observation Solutions

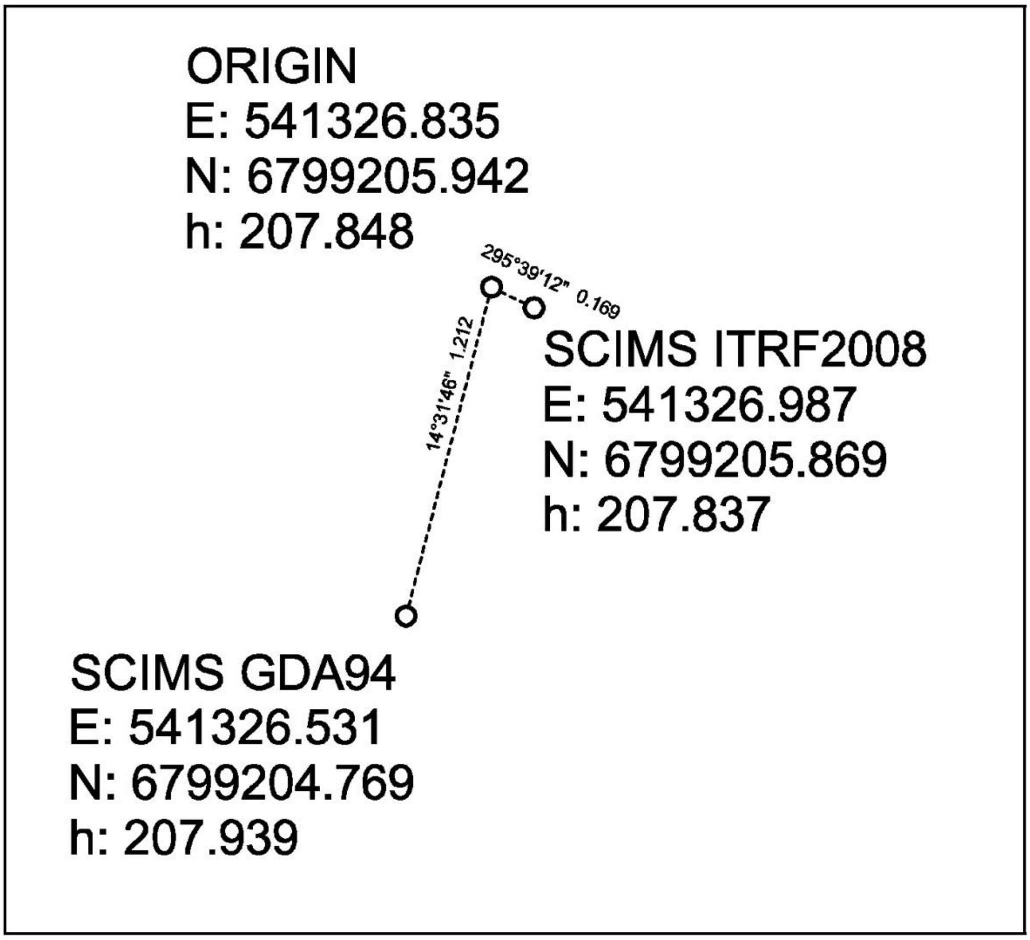

Figure 4.3 Plot of Comparison of SCIMS Coords, SCIMS Coords Transformed to ITRF2008 and the Average of the Processed Solutions (Origin) at Meerschaum Trig Station

Figure 4.3 shows the separation between the SCIMS GDA94 coordinates, the SCIMS coordinates transformed to ITRF2008 and the average of the twenty-four-hour solutions (Origin) derived from the various service providers at Meerschaum Trig Station. Tables 4.5, 4.6, 4.7 and 4.8 include the twenty-four-hour observation solutions from each service provider for each of the three survey dates (A, B & C) at each Trig Station. Figure, 4.4 is a plot of these solutions with the average of the solutions used as an origin from which to make comparisons.

Table 4.5 AUSPOS 24hr Observation Solutions - Meerschaum Trig

AUSPOS			
24hr A	541326.833	6799205.947	207.847
24hr B	541326.836	6799205.945	207.846
24hr C	541326.834	6799205.947	207.849
Avg 24hr	**541326.834**	**6799205.946**	**207.847**

Table 4.6 OPUS 24hr Observation Solutions – Meerschaum Trig

OPUS			
24hr A	541326.830	6799205.941	207.853
24hr B	541326.840	6799205.939	207.858
24hr C	541326.835	6799205.942	207.848
Avg 24hr	**541326.835**	**6799205.941**	**207.853**

Table 4.7 CSRS 24hr Observation Solutions – Meerschaum Trig

CSRS			
24hr A	541326.837	6799205.940	207.843
24hr B	541326.837	6799205.943	207.855
24hr C	541326.832	6799205.943	207.841
Avg 24hr	**541326.835**	**6799205.942**	**207.846**

Table 4.8 Magic 24hr Observation Solutions – Meerschaum Trig

Magic			
24hr A	541326.840	6799205.940	207.845
24hr B	541326.851	6799205.940	207.851
24hr C	541326.851	6799205.940	207.845
Avg 24hr	**541326.847**	**6799205.940**	**207.847**

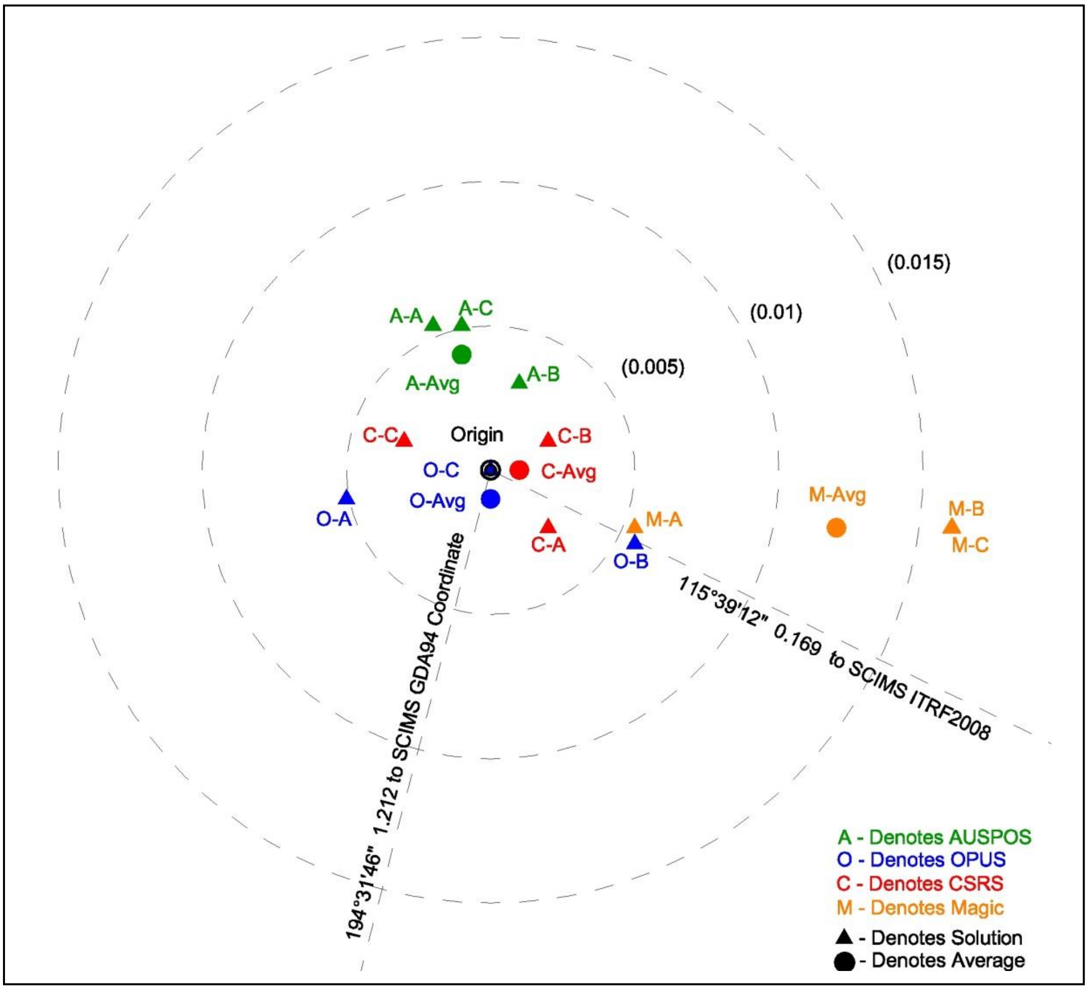

Figure 4.4 Plot of 24hr Solutions - Meerschaum Trig

A similar result is seen with the solutions for Meerschaum Trig Station to those observed at Hayter Trig Station. The easting coordinates are within 21mm, northing coordinates within 8mm and ellipsoidal heights within 17mm. As illustrated in Figure 4.4, the Magic solutions are biased to the east, the AUSPOS solutions biased to the North and OPUS solutions biased to the south. The CSRS solutions however, are plotted around the origin all within 3mm .

4.3 Solutions by Observation Length

A full table of solutions is provided in Appendix B and includes the solutions from each service provider from observation files decimated into one-hour, two-hour, four-hour, six-hour, eight-hour, twelve-hour and twenty-four-hour lengths. The purpose of which is to observe the effects of accuracy and precision as observation length increases.

4.3.1 Residuals by observation length

Tables 4.9 and 4.10 include the residuals of solutions from the calculated origin for each observation length. These will be utilised in Chapter 5 to undertake statistical analysis to examine precision and accuracy of the solutions as observation time increases.

Table 4.9 Residuals by Observation Length - Hayter Trig Station

	AUSPOS			OPUS			CSRS-PPP			MAGIC-GNSS		
	ΔE	ΔN	Δh	ΔE	ΔN	Δh	ΔE	ΔN	Δh	ΔE	ΔN	Δh
1hr A	-0.029	-0.026	0.127		*		-0.016	0.012	-0.021	-0.013	0.012	0.055
2hr A	-0.001	0.007	0.012		*		-0.010	0.003	-0.008	-0.002	-0.001	0.034
4hr A	-0.001	0.005	0.012	-0.007	-0.005	0.017	-0.005	0.003	-0.006	0.001	0.003	0.010
6hr A	-0.001	0.004	0.007	-0.005	-0.002	0.013	-0.005	0.003	0.000	0.003	-0.001	0.013
8hr A	-0.001	0.004	0.007	-0.004	-0.001	0.013	-0.008	0.003	0.005	0.006	-0.001	0.011
12hr A	0.000	0.004	0.000	-0.003	-0.001	0.007	-0.005	0.003	-0.004	0.006	-0.001	0.012
24hr A	0.000	0.004	0.000	-0.001	-0.003	0.002	-0.005	-0.001	-0.005	0.006	-0.001	0.003
1hr B	0.003	-0.003	-0.017		*		-0.028	0.004	0.064	-0.012	0.001	0.029
2hr B	-0.007	-0.002	0.028	-0.015	-0.025	0.004	-0.025	0.004	0.034	-0.001	0.001	0.022
4hr B	-0.004	0.003	0.004	-0.010	0.000	0.018	-0.017	0.004	0.010	0.002	0.004	0.009
6hr B	-0.003	0.002	-0.002	-0.006	-0.001	0.010	-0.014	0.004	0.003	0.002	0.001	0.009
8hr B	-0.002	0.002	-0.006	-0.005	-0.001	0.008	-0.006	0.000	-0.001	0.007	-0.003	0.007
12hr B	-0.001	0.002	-0.012	-0.005	-0.001	-0.003	-0.006	0.004	-0.003	0.007	0.000	0.005
24hr B	-0.003	0.003	-0.006	-0.003	-0.002	0.000	-0.006	0.000	0.004	0.010	0.000	0.002
1hr C	-0.010	0.000	0.006		*		-0.020	0.003	0.003	0.018	-0.001	-0.005
2hr C	-0.002	0.003	0.002	-0.006	0.002	0.002	-0.012	0.003	0.001	0.029	-0.001	-0.011
4hr C	-0.005	0.000	0.005	-0.008	0.000	0.005	-0.009	0.003	0.005	0.016	-0.004	-0.006
6hr C	-0.005	0.002	0.010	-0.009	-0.001	0.008	-0.014	0.003	0.010	0.007	-0.004	0.001
8hr C	-0.004	0.002	0.009	-0.008	0.000	0.011	-0.012	0.003	0.009	0.010	-0.004	-0.002
12hr C	-0.002	0.001	-0.002	-0.006	-0.001	0.005	-0.003	0.003	-0.004	0.000	-0.004	0.000
24hr C	-0.002	0.001	0.002	-0.007	-0.001	0.006	-0.003	0.003	-0.005	0.012	-0.004	-0.004

* Opus will not process files shorter than 2 hours, one of the two hour files at Hayter Trig contained insufficient data to enable processing.

Table 4.10 Residuals by Observation Length - Meerschaum Trig Station

	AUSPOS			OPUS			CSRS-PPP			MAGIC-GNSS		
	ΔE	ΔN	Δh	ΔE	ΔN	Δh	ΔE	ΔN	Δh	ΔE	ΔN	Δh
1hr A	-0.006	0.004	-0.007	*			-0.017	0.001	-0.003	0.005	0.004	-0.012
2hr A	-0.008	0.003	0.012	-0.015	-0.004	0.013	-0.022	0.001	0.022	0.002	0.005	0.003
4hr A	-0.005	0.005	-0.009	-0.008	0.000	-0.011	-0.014	0.001	0.004	0.005	0.001	-0.017
6hr A	-0.003	0.005	0.002	-0.005	0.002	-0.003	-0.009	0.001	0.002	0.008	-0.002	-0.020
8hr A	-0.002	0.004	-0.001	-0.005	0.000	-0.004	-0.003	0.001	-0.006	0.005	-0.002	-0.019
12hr A	-0.002	0.005	-0.005	-0.005	-0.001	0.001	0.002	0.001	-0.012	0.005	-0.002	-0.004
24hr A	-0.002	0.005	0.000	-0.005	-0.001	0.006	0.002	0.001	-0.012	0.005	-0.002	-0.002
1hr B	-0.010	-0.005	0.011	*			-0.023	0.005	0.001	0.015	0.008	-0.029
2hr B	-0.007	0.001	-0.003	-0.010	0.000	0.002	-0.007	0.001	-0.012	0.018	0.004	-0.029
4hr B	-0.005	-0.001	-0.012	-0.010	-0.003	-0.001	-0.009	0.001	-0.016	-0.001	0.001	-0.011
6hr B	-0.005	0.000	-0.015	-0.008	-0.007	0.003	-0.004	0.001	-0.015	0.007	-0.002	-0.006
8hr B	-0.003	0.001	-0.016	-0.008	-0.003	0.003	-0.001	0.001	-0.015	0.010	-0.002	-0.001
12hr B	-0.004	0.002	-0.018	-0.008	-0.003	0.003	-0.004	0.001	-0.011	0.010	-0.002	0.000
24hr B	-0.005	0.003	-0.007	-0.001	-0.003	0.005	-0.004	0.001	0.002	0.010	-0.002	-0.002
1hr C	0.000	0.005	-0.015	*			-0.012	0.003	-0.008	0.029	-0.003	-0.019
2hr C	-0.002	0.004	-0.003	-0.002	0.001	0.000	-0.006	0.003	0.002	0.010	-0.003	-0.005
4hr C	-0.004	0.004	0.000	-0.008	0.001	0.006	-0.006	0.003	0.005	0.013	-0.003	0.001
6hr C	-0.004	0.004	0.003	-0.007	0.002	0.009	-0.012	0.003	0.013	0.010	-0.006	0.002
8hr C	-0.004	0.004	0.000	-0.006	0.001	0.004	-0.006	0.003	0.008	0.010	-0.006	0.002
12hr C	-0.004	0.004	-0.002	-0.008	0.000	0.004	-0.004	0.000	-0.004	0.010	-0.006	0.007
24hr C	-0.004	0.004	0.003	-0.003	-0.001	0.002	-0.006	0.000	-0.005	0.013	-0.003	-0.001

* Opus will not process files shorter than 2 hours.

As can be seen in Tables 4.9 and 4.10 the one-hour observation residuals are typically greater than those from the two-hour files and longer. This was expected as AUSPOS issues a caution with their report stating that ambiguities have not been resolved for the one-hour solution. CSRS shows the 95% confidence interval of the solution to be in the order of 25mm 40m and 82mm in E, N, and ellipsoidal height respectively. Opus will not process one-hour files in this region but provides a percentage of ambiguities resolved in the longer observation solutions (which increase as observation length increases) and Magic does not provide any specific cautionary statement.

It is possible that a large proportion of the error in the one-hour solutions is attributable to ambiguity. However the relatively larger residuals seen at Hayter Trig Station in session A may be attributable to some other source. Investigation into the processing method did not identify any external source of error with regards to incorrect instrument heights, data entry error or any other source of human error associated with data processing. Data was processed a second time to check for anomalies with no change in solution. Crawford (2013, pp. 146-147) examined the effects of a seagull or similar sized bird sitting on a receiver antenna. He found that there was more pronounced height variation and an increase in noise in the solution. He found that the standard deviation of the heights at least doubled and the amplification of noise was by a factor of 3 at the minimum and 6 at the maximum. The presence of bird faeces was discovered on the antenna after the session so this may account for the unusual results but cannot be confirmed. Also, solar activity could play a part but since session A was not conducted concurrently for both trig stations, the data cannot be compared for similar distortions or anomalies.

4.4 Solution by Data Type

The following tables are a comparison of GPS and GNSS solutions derived from CSRS and Magic. These were the only service providers in the study that processed both GPS and GLONASS data.

Table 4.11 Comparison of 24hr GPS and GNSS Solutions - Hayter Trig Station

	CSRS-PPP			MAGIC-GNSS		
	E	N	h	E	N	h
GPS A	558577.886	6827643.442	154.859	558577.891	6827643.435	154.867
GPS B	558577.877	6827643.439	154.857	558577.894	6827643.439	154.855
GPS C	558577.885	6826143.442	154.869	558577.896	6827643.432	154.864
Avg GPS	**558577.883**	**6827143.441**	**154.862**	**558577.894**	**6827643.435**	**154.862**
GNSS A	558577.880	6827643.435	154.861	558577.891	6827643.435	154.869
GNSS B	558577.883	6827643.438	154.864	558577.899	6827643.438	154.862
GNSS C	558577.886	6827643.442	154.864	558577.901	6827643.435	154.865
Avg GNSS	**558577.883**	**6827643.438**	**154.863**	**558577.897**	**6827643.436**	**154.865**

The CSRS solutions at Hayter Trig show the range of GPS coordinates to be within 9mm in easting, 3mm in northing and 12mm in height. For GNSS coordinates, the ranges are within 6mm in easting, 7mm in northing and 3mm in height. For Magic solutions, the range of GPS coordinates is within 5mm in easting, 7mm in northing and 12mm in height. For the GNSS coordinates, 10mm in easting, 3mm in northing and 7mm in height.

Table 4.12 Comparison of 24hr GPS and GNSS Solutions - Meerschaum Trig Station

	CSRS-PPP			MAGIC-GNSS		
	E	N	h	E	N	h
GPS A	541326.837	6799205.943	207.843	541326.837	6799205.937	207.844
GPS B	541326.834	6799205.943	207.857	541326.851	6799205.940	207.851
GPS C	541326.834	6799205.943	207.837	541326.848	6799205.937	207.843
Avg GPS	**541326.835**	**6799205.943**	**207.846**	**541326.845**	**6799205.938**	**207.846**
GNSS A	541326.837	6799205.940	207.843	541326.840	6799205.940	207.845
GNSS B	541326.837	6799205.943	207.855	541326.851	6799205.940	207.851
GNSS C	541326.832	6799205.943	207.841	541326.851	6799205.940	207.845
Avg GNSS	**541326.836**	**6799205.942**	**207.846**	**541326.847**	**6799205.940**	**207.847**

The CSRS solutions at Meerschaum Trig show the range of GPS coordinates to be within 3mm in easting, 0mm in northing and 20mm in height. For GNSS coordinates, the ranges are within 5mm in easting, 3mm in northing and 14mm in height. For Magic solutions, the range of GPS coordinates is within 14mm in easting, 3mm in northing and 8mm in height. For the GNSS coordinates, 11mm in easting, 0mm in northing and 4mm in height.

Figures 4.5 and 4.6 show a plot of the solutions for each trig station. The CSRS solutions at Meerschaum Trig are noticeably closer to the origin and have a much smaller spread than the other examples. Whilst the accuracy of the CSRS solutions appears to be similar at Meerschaum Trig, the GPS solutions are slightly more precise. The accuracy and precision of the other solutions at each trig station don't appear to be noticeably more accurate or precise. The data will be statistically analysed in the next chapter to more closely inspect performance.

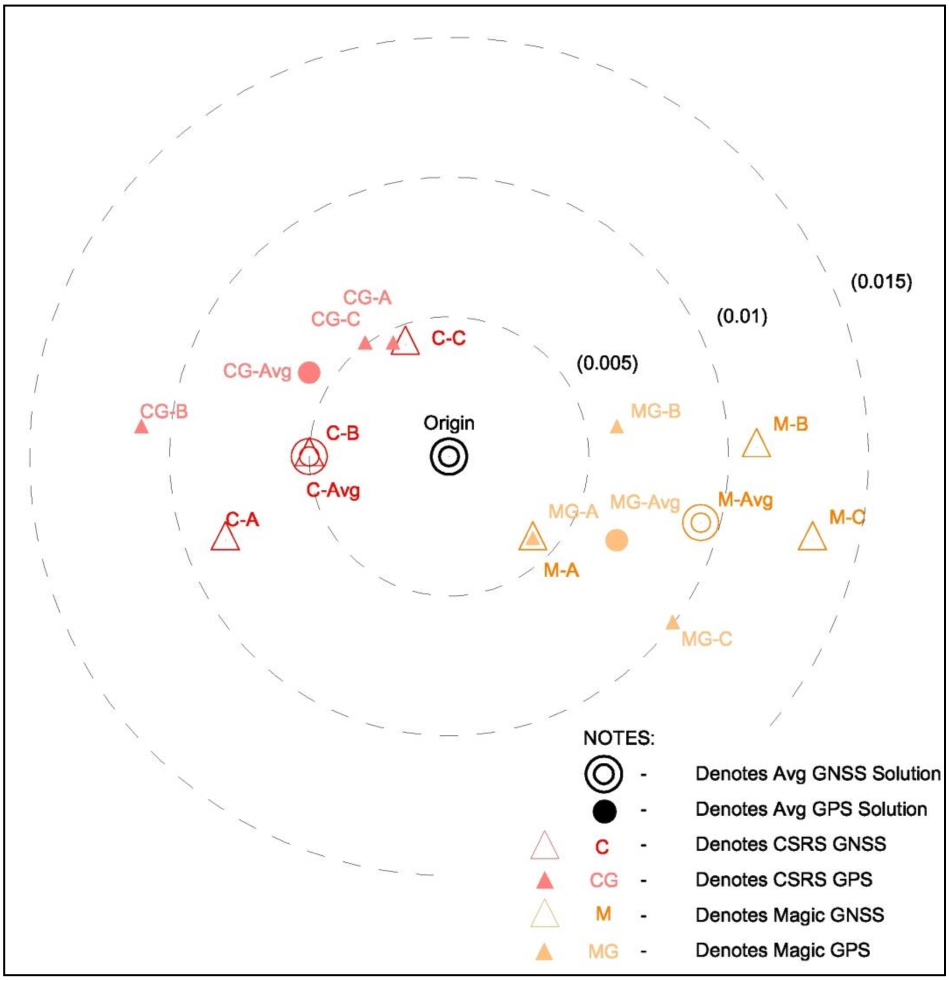

Figure 4.5 Plot of GPS vs GNSS Solutions – Hayter Trig

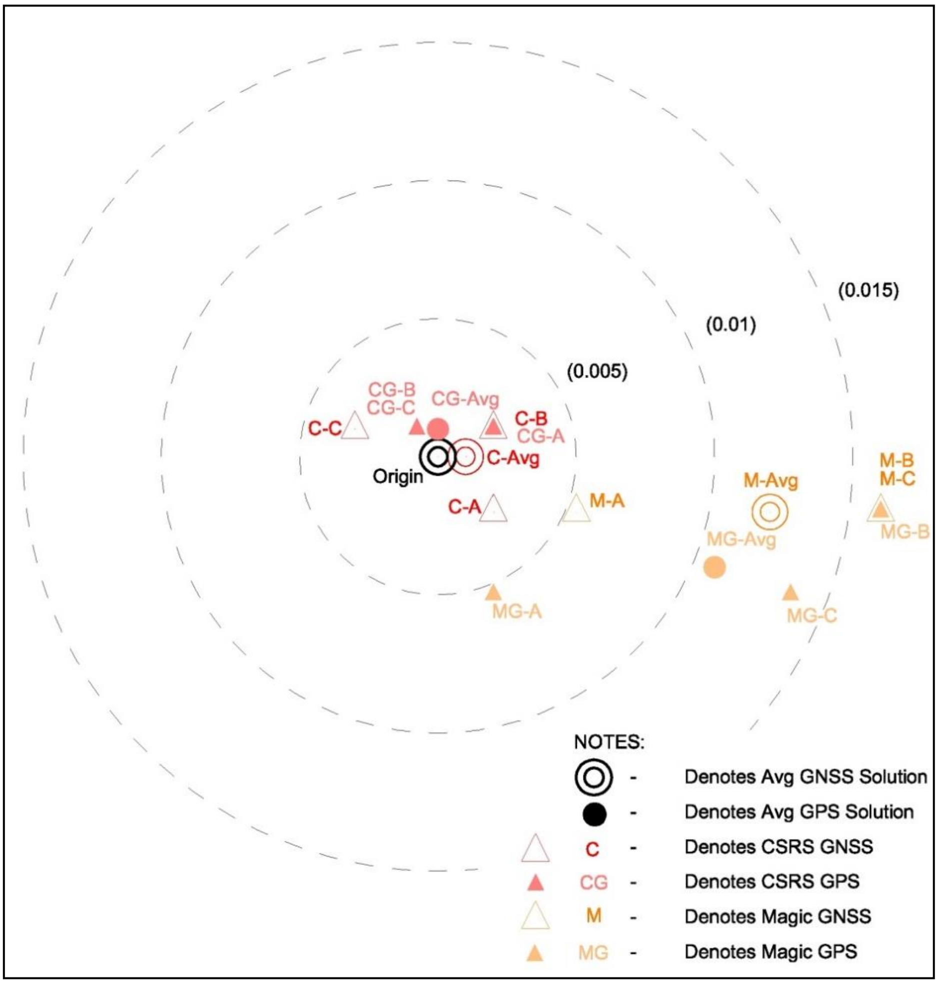

Figure 4.6 Plot of GPS vs GNSS Solutions – Meerschaum Trig

4.5 Summary

Chapter 4 has provided an illustration of the solutions derived from the various service providers. It is clear that the solutions are all similar and repeatable at varying degrees of precision. What is also clear is the evidence of bias in solutions. This will be looked at in the Chapter 5.

CHAPTER 5 – DATA ANALYSIS

5.1 Introduction

The Aim of this chapter will be to give meaning to the results of data capture and statistical analysis. At the conclusion of this chapter the reader should have an understanding of the performance of the respective service providers and the suitability for their use in the North Coast region of NSW. It should provide greater understanding of the bias observed in the results in Chapter 4 and to what extent this affects accuracy and precision. It should also provide some comparison with previous studies and contribute to the weight of those findings.

In order to achieve this, solutions from each service provider presented in Chapter 4 will be statistically analysed and a variety of comparisons made in order to compare performance. Specifically these will include the examination of solutions over observation length, the comparison of differential baseline services to PPP services and the comparison of GPS derived solutions to GNSS derived solutions. Also, comparisons will be made between results of this study and those of previous studies in order to address some of the conflicting findings.

At the conclusion of this chapter, the reader should have an understanding of the performance characteristics of each service provider relative to one another and to the calculated "truth".

5.2 Three-Hour Solution Comparison

In this section, the residuals of the solutions are calculated from the origin and presented for analysis. In order to undertake the statistical analysis, the raw data files were dissected into three-hour observation files. The three-hour observation files were necessary as OPUS would not process one-hour files and not all the two-hour files were successfully processed It also enabled better opportunity to resolve for ambiguity. Tables 5.1 and 5.2 include the residuals of the solutions calculated from the origin for each three hour block of time for each of the 3 survey sessions at each trig station.

5.2.1 Residuals

Residuals were calculated for each solution from each service provider and the averages determined. The maximum and minimum residuals were determined from the sample data, the sample standard deviation of each service provider was calculated followed by the 95% confidence figure. From this, the upper and lower bounds of the confidence interval were determined for each service provider and this data plotted in graphs in order to make a determination about accuracy and precision.

Tables C1 & C2 in Appendix C present the three-hour residuals for each service provider, for each survey session, at each site. It is important to note that these residuals are calculated against the origin, the calculated “truth” for each site as explained in Chapter 4 above.

Figures 5.1 and 5.2 are plots of the 95% confidence intervals for the residuals incorporating the average solution as well as the range of residuals observed. The horizontal bars in the centre of each column represent the combined average residual for each coordinate element. The closer this bar is to zero the more accurate the solution relative to the calculated origin. The coloured columns represent the spread of 95% confidence intervals and the whiskers above and below the columns represent the range of residuals. The smaller the columns, the smaller the 95% confidence interval and thus the more precise the solution. The smaller the whiskers, the closer the solutions are to the real solution (ie the smaller the variations of solutions from the real solution).

What is evident from these figures is that the AUSPOS solutions have a smaller range of residuals and a smaller 95% confidence interval and thus provide a more precise solution. Evident among all solutions is that the easting coordinates are less precise than the northing coordinates. With the exception of AUSPOS, there is a substantial level of difference between easting and northing precision. As expected, heights reveal a much greater magnitude of error than the horizontal coordinates for all services. The average residuals are indicative of the accuracy of the solutions compared to the calculated origin. From the figures it can be seen that AUSPOS, OPUS and CSRS have a similar accuracy in the horizontal position. Heights are less accurate and less reliable with the OPUS solutions as can be seen by the larger range of residuals, larger 95% confidence interval and the difference between the average solution and 0.0.

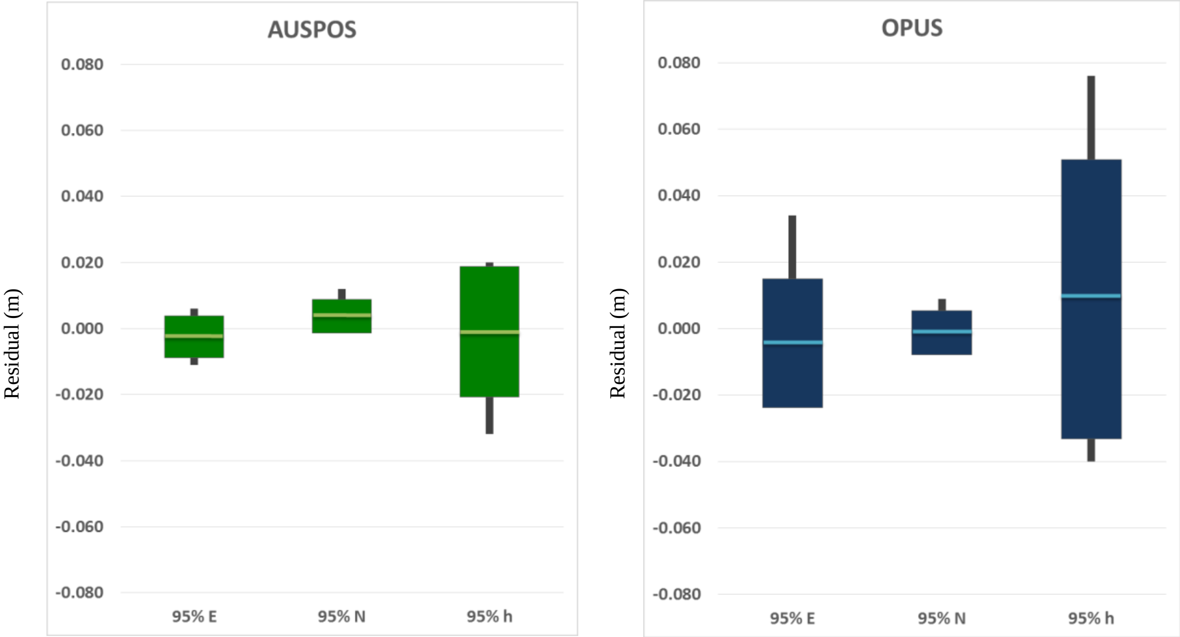

Figure 5.1 95% Confidence Interval of Residuals - Differential Baseline Solutions

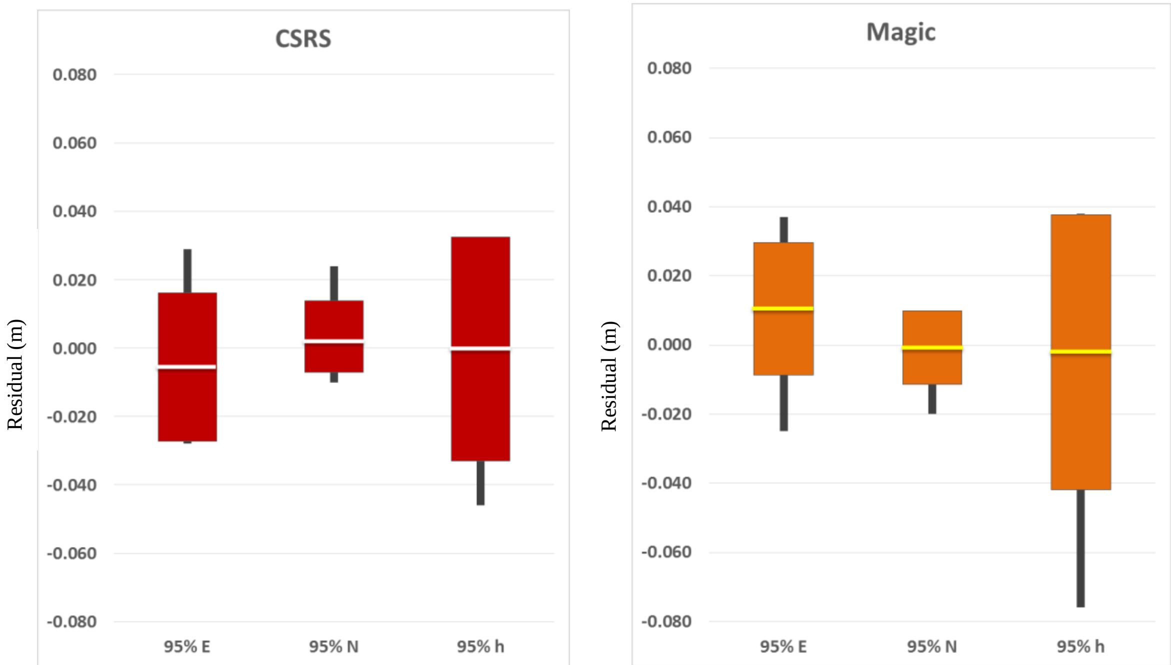

Figure 5.2 95% Confidence Interval of Residuals - PPP Solutions

5.2.2 Repeatability

When analysing repeatability, we are aiming to test the ability of each service provider to repeatedly process data from the same location and produce the same or similar results each time an observation session is conducted. By looking at the twenty-four-hour observation solutions and the three-hour residuals, we can conclude that the AUSPOS service provides a very reliable and repeatable solution. The range of coordinate differences for the twenty-four-hour solutions is shown in table 5.3 below.

Table 5.1 Solution Residuals

Service Provider	Survey Site	ΔE	ΔN	Δh
AUSPOS	Hayter	0.002	0.001	0.017
	Meerschaum	0.003	0.002	0.003
OPUS	Hayter	0.004	0.005	0.015
	Meerschaum	0.010	0.003	0.010
CSRS	Hayter	0.006	0.007	0.003
	Meerschaum	0.005	0.003	0.014
Magic	Hayter	0.010	0.003	0.007
	Meerschaum	0.011	0.000	0.006

Figures 5.1 and 5.2 show that repeatability at 95% confidence is in the order of 15mm for AUSPOS for position and 40mm for height, OPUS shows 40mm for position and 80mm for height, CSRS shows 45mm for position and 65mm for height and Magic shows 40mm for position and 80mm for height

5.3 Differential Baseline vs PPP

In this section the solutions are combined according to processing method in order to ascertain the performance of differential baseline processing against true PPP processing.

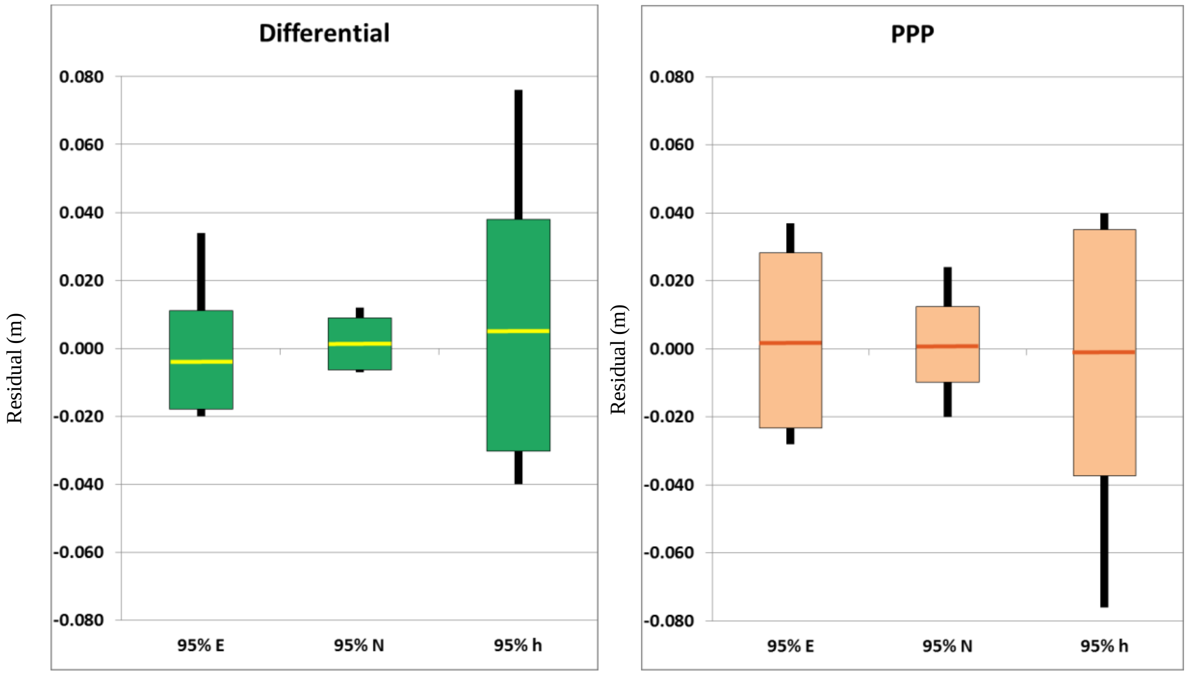

Figure 5.3 Combined 95% Confidence Interval of Residuals – Differential Baseline vs PPP

When the solutions are combined according to processing method, it can be seen that the differential method shows a better level of precision than PPP in horizontal components but only slightly better in the height component. The spread of the height residuals is similar but PPP is trending to a height lower than the average whilst the differential solutions are trending towards a height greater than the average.

5.4 GPS vs GNSS

Table 5.2 GPS Average Solutions - 3hr Residuals

GPS Solution	CSRS-GPS			MAGIC - GPS		
	ΔE	ΔN	Δh	ΔE	ΔN	Δh
Avg	-0.007	0.006	-0.001	0.009	-0.002	-0.007

Table 5.3 GNSS Average Solutions - 3hr Residuals

GNSS Solution	CSRS-GNSS			MAGIC-GNSS		
	ΔE	ΔN	Δh	ΔE	ΔN	Δh
Avg	-0.006	0.003	0.000	0.010	-0.001	-0.002

Table 5.2 presents the average three-hour residuals for CSRS and Magic Solutions derived from GPS only data. Table 5.3 presents the average three-hour residuals for GNSS data. Tables C1, C2 and C3 in Appendix C provide a full list of the three-hour residuals. These are used in the preparation of the graphs below. Figures 5.4, 5.5 and 5.6 graph the comparison of the 95% confidence intervals of the residuals.

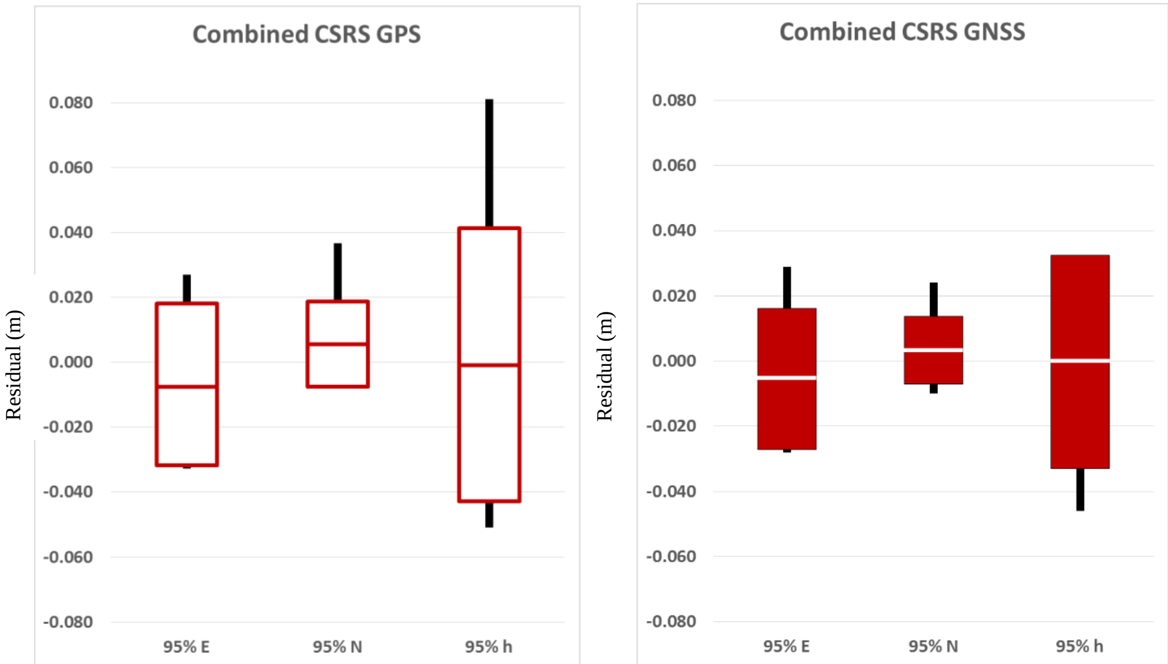

Figure 5.4 95% Confidence Interval of Residuals - CSRS GPS vs CSRS GNSS

The comparison of CSRS GPS and GNSS solutions indicates a slightly better precision with the GNSS based solutions. The accuracy of solutions compared to the calculated origin is very similar.

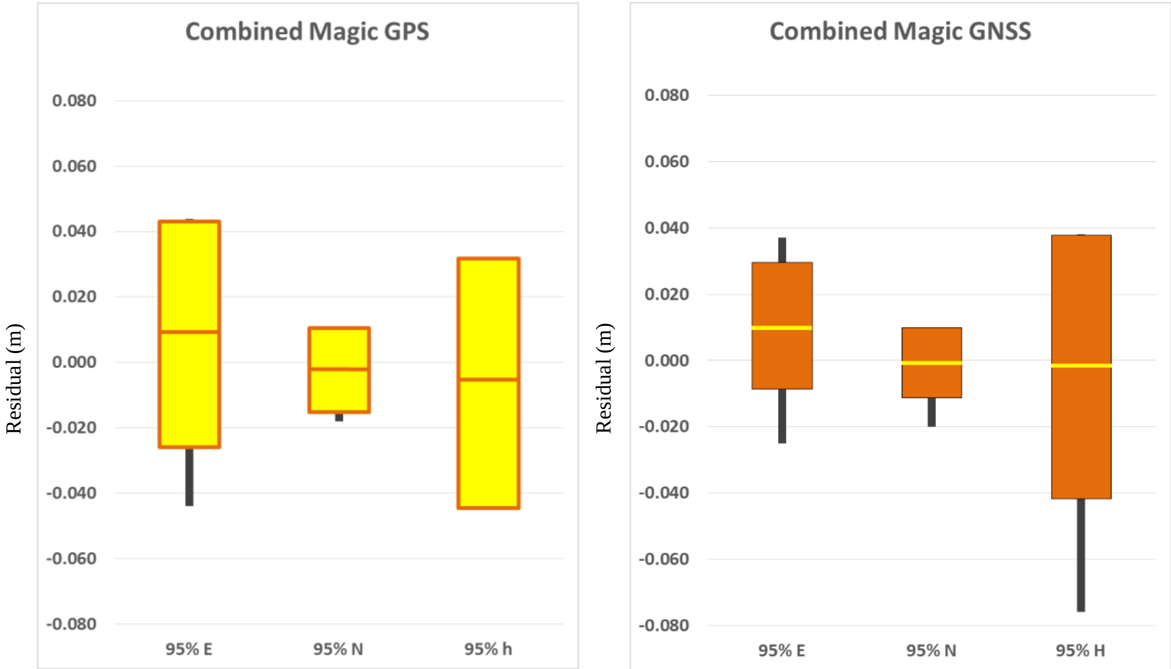

Figure 5.5 95% Confidence Interval of Residuals – Magic GPS vs Magic GNSS

The magic solutions reflect that of the CSRS solutions. The horizontal GNSS coordinates are more precise than the GPS coordinates however the height component is less precise with the GNSS coordinate and shows a much greater spread of the outliers.

When the respective solutions are combined according to data type (see Figure 5.6), it is clear to see that the GNSS based solutions offer a more precise alternative for horizontal position. With regards to height, the GNSS solutions offer a slightly better precision and slightly lesser spread of the outliers.

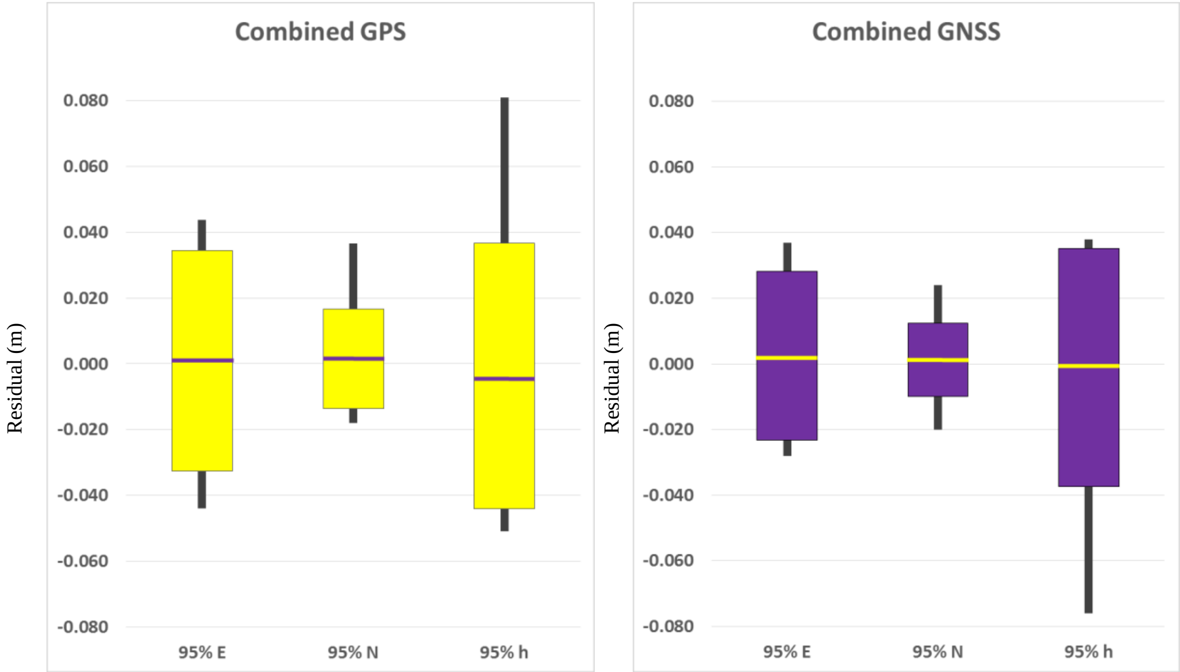

Figure 5.6 95% Confidence Intervals of Residuals – Combined GPS vs Combined GNSS

When comparing this data to the conclusion of Cai & Gao (2012) there is an interesting finding. Their study compared GPS to GLONASS solutions and determined GPS provided more accurate results, most likely due to the better availability of the GPS constellation. This study has combined GPS and GLONASS data for comparison with GPS only data and found that this provides a similar accuracy with respect to the calculated Origin but with better precision.

5.6 Observation Time Comparison

The aim of this section is to see if the results obtained in this study reflect those of previous studies in terms of accuracy and precision. In addition, this study is hoping to identify and explain a bias in solutions as was identified in Cleaver (2013) by repeating a similar analysis of the observation data.

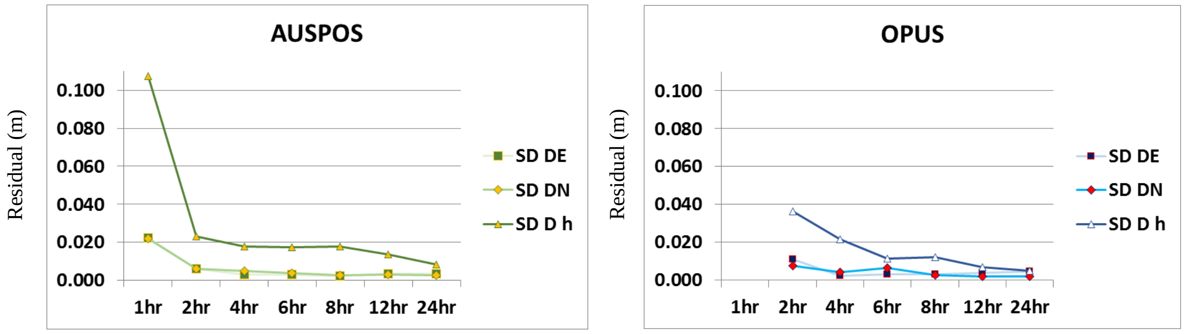

Figure 5.7 Comparison of Coordinate Residuals to Observation Time – Differential Baseline Solutions

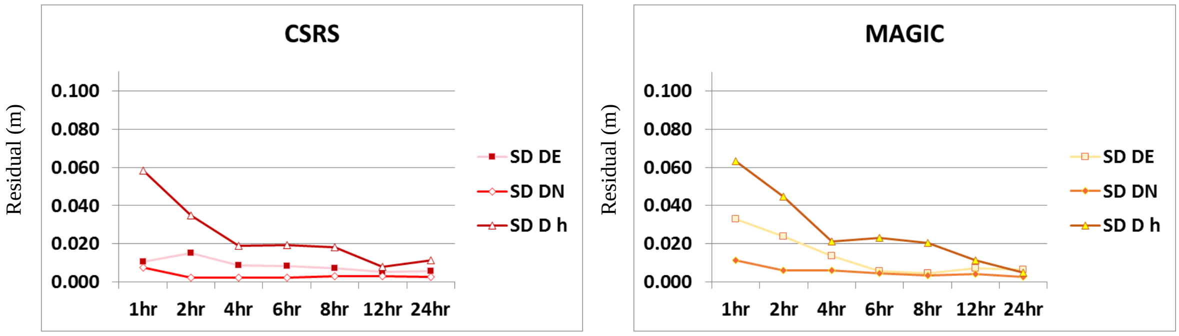

Figure 5.8 Comparison of Coordinate Residuals to Observation Time – PPP Solutions

Figures 5.7 and 5.8 plot the combined residuals over observation length for each service provider. Unsurprisingly, the results of this study reflect those of Cleaver, Silver and Tsakiri. The twenty-four-hour solutions were very similar for all service providers although the Magic Solutions were clearly different to the others. The height component of the coordinates continues to improve in all solutions for the twenty-four-hour observation period. Whilst there is steady improvement in the horizontal coordinates in the first four to six hours, the rate of improvement is significantly less or minimal after that time.

5.5 Solution Bias

As seen in Figures 4.2 and 4.4 this study observed bias in solutions which was mentioned in Chapter 4. In order to produce a solution, AUSPOS utilises the IGS08 reference frame and the APREF. Seven IGS08 core sites are utilised along with eight non IGS08 core sites in closest proximity to the surveyed mark. This enables the formation of a denser reference network. The dense network enables the generation of a reliable regional ionospheric delay model and tropospheric corrections to support and improve ambiguity resolution (Dawson et al, 2014). OPUS, utilising only 3 sites, has a much less dense reference network and thus would not have the same ability to model ionospheric delay or generate tropospheric corrections and thus would not have the same capacity to improve ambiguity resolution.

In addition, the reference stations utilised by AUSOS in these solutions were situated in various locations surrounding the surveyed sites in all directions. They included reference stations within 100km and also stations many thousands of kilometres away. OPUS utilised only three stations in its solution calculations, all of which were many hundreds of kilometres away and all of which were situated to the south of the surveyed sites.

A typical list of reference stations utilised in the AUSPOS solutions included 15 of the following; Woolloongabba, Cleveland, Beaudesert, Robina, Casino, Ballina, Grafton, Yamba Coffs Harbour, Tenterfield, Tidbinbilla, Ceduna Alice Springs, Melbourne, Hobart, Macquarie Island, Koumac in New Caledonia and Auckland in New Zealand. OPUS, relying on only three stations, utilised any three of the following; Stromlo, Sydney, Tidbinbilla, and Parkes. The geometry of the baselines could be a significant contributor to the observed bias. However, the results of the twenty-four-hour solutions ranged from only a few millimetres up to ten millimetres in difference in horizontal position to AUSPOS.

When reviewing the two PPP solutions, the CSRS solutions do not demonstrate a conclusive pattern of bias and were within ten millimetres in horizontal position from OPUS and AUSPOS solutions. The Magic Solutions however, are as much as twenty-one millimetres different to the other solutions. This is not a great difference but in relation to the solutions received from the other providers it is clear there is some inherent difference in how the Magic solutions are conceived. The results suggest that the Magic PPP service is certainly less reliable in this region and would not be the ideal choice of service for data processing.

5.6 Summary

The analysis of results has demonstrated that the solutions are all similar. It is clear that longer observations produce better results, which supports previous research. It is also clear that a bias is evident in the solutions and that the CORS utilised in the calculation of corrections and baselines is influential in this bias. As has been found in previous studies, AUSPOS is the preferred option for use. However, comparable results are obtainable using OPUS and CSRS, particularly where long observation periods are possible. Magic solutions whilst being similar to the others are substantially different in the context of all solutions generated which suggests that it is less suitable for use in this region.

CHAPTER 6 – CONCLUSION

6.1 Introduction

The aim of this study has been to evaluate the performance of four online post processing services by processing identical data and comparing the results of solutions these services provided. To this end it has highlighted the fact that AUSPOS, OPUS, CSRS-PPP and MagicPPP all provide very similar solutions but Magic is not as suitable for use in this region.

6.2 Recommendations

Static single receiver surveys are possible with a high degree of accuracy, precision and reliability. Observation sessions should be in the order of six hours at least in order to develop a reliable horizontal solution and in excess of twenty-four hours or as long as possible for height realisation. Previous studies have utilised one-hour observation files in order to conduct statistical analysis and this study analysed three-hour files. A possible option for future study might be to process six-hour files as this observation length has been found to provide reliable horizontal solutions.

The inclusion of additional PPP service providers would be beneficial in testing the findings of this report. It would be ideal to include the Trimble RTX PPP service in solution processing. RTX has been specifically developed for use in Australia and therefore should provide reliable results. RTX could not be used in this study as the GNSS antennas were not compatible with the RTX service.

6.3 Conclusion

The study set out to comment on accuracy and precision of the services but discovered that the state survey coordinates are not necessarily an accurate representation of true position today and thus are not suitable for assessing the accuracy of the results. The comments on accuracy are only relevant to an assumed "truth" determined by an average of all the solutions retrieved. Therefore, if a survey is conducted in the northern rivers of NSW and requires accurate connection to the SCIMS network, the survey must be connected to the network in the field by observing marks with known coordinates.

What is clear from the results is that the AUSPOS solution was more precise in horizontal position. The other solutions all showed a similar level of precision to one another but the

Magic solutions were very different to the others and not considered as accurate relative to the adopted "truth". The bias that exists in the Magic solutions is significant enough not to recommend its use in this region. The results also suggest that AUSPOS, OPUS CSRS and Magic all provided repeatable solutions from multiple days of observations but AUSPOS was substantially more precise and therefore demonstrated better repeatability.

Cia and Gao found that a GPS solution was more accurate than a GLONASS solution. When looking at the inclusion of GLONASS data in coordinate realisation, it is apparent from the results of this study that solution accuracy is not detrimentally affected nor does it appear to provide any improvement in accuracy. What it does impact upon is the precision of the solution. It was found that the precision of the GNSS solution is better than the GPS only solution. It is surmised that this is due to the availability of more satellites at any particular time and thus better geometry of the satellites throughout the observation session. This would need to be followed up in future research.

There has been a variety of research and recommendations according to the length of observation time on the accuracy and precision of a solution from these online post processing systems. This study has confirmed some of the results found by Cleaver, Silver and Tsakiri. Horizontal solutions improved rapidly in the first four hours but after six hours the rate of improvement was minimal. Heights continued to improve throughout the twenty-four-hour period and approached the horizontal residuals by the end of the observation session.

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APPENDICES

Appendix A Project Specification

University of Southern Queensland

Faculty of Engineering and Surveying

<u>ENG4111/4112 Research Project</u>

Project Specification

STUDENT: DANIEL O'SULLIVAN

TOPIC: COMPARISON OF PRECISE POINT POSITIONING SERVICES

SUPERVISOR: PETER GIBBINGS

ENROLLMENT: ENG4111- S1, 2014 ENG4112-S2, 2014

PROJECT AIM: Evaluate and compare the performance of Precise Point Positioning (PPP) and differential baseline methods of online post processing services when processing data captured over extended periods of time and in multiple data collection sessions. This will be achieved by statistically analysing the accuracy and precision of processed solutions, comparing solutions from each method of post processing to identify any bias and comparing solutions to known coordinates.

PROGRAMME: Issue A - 12 March 2014

1. Establish background knowledge of geodetic surveying practices, data collection methods, equipment and post processing services.
2. Research the differences between true PPP and differential GNSS post processing services. Identify service providers and research methods of on line post processing (eg Trimble's RTX, CSRS from Natural Resources Canada, Auspos, Scout)
3. Research Statistical Analysis
4. Develop a method for data collection
5. Examine and statistically analyse data

6. Evaluate results of data analysis to determine if any bias exists between the different methods of post processing.
7. Compare post-processed solutions to known coordinates to evaluate accuracy and precision of solutions
8. Examine repeatability of results by comparing solutions from data collected over multiple sessions and multiple days

AGREED ____________________ (Student) ____________________ (Supervisor)

Date:

Appendix B Solutions by Observation Length

Table B1 Hayter Trig Station Coordinates by Observation Length

	AUSPOS			OPUS			CSRS-PPP			MAGIC-GNSS		
	E	N	h	E	N	h	E	N	h	E	N	h
1hr A	558577.856	6827643.410	154.993	*			558577.869	6827643.448	154.845	558577.872	6827643.448	154.921
2hr A	558577.884	6827643.443	154.878	*			558577.875	6827643.439	154.858	558577.883	6827643.435	154.900
4hr A	558577.884	6827643.441	154.878	558577.878	6827643.431	154.883	558577.880	6827643.439	154.860	558577.886	6827643.439	154.876
6hr A	558577.884	6827643.440	154.873	558577.880	6827643.434	154.879	558577.880	6827643.439	154.866	558577.888	6827643.435	154.879
8hr A	558577.884	6827643.440	157.873	558577.881	6827643.435	154.879	558577.877	6827643.439	154.871	558577.891	6827643.435	154.877
12hr A	558577.885	6827643.440	154.866	558577.882	6827643.435	154.873	558577.880	6827643.439	154.862	558577.891	6827643.435	154.878
24hr A	558577.885	6827643.440	154.866	558577.884	6827643.433	154.868	558577.880	6827643.435	154.861	558577.891	6827643.435	154.869
	E	N	h	E	N	h	E	N	h	E	N	h
1hr B	558577.892	6827643.435	154.843	*			558577.861	6827643.442	154.924	558577.877	6827643.439	154.889
2hr B	558577.882	6827643.436	154.888	558577.874	6827643.431	154.904	558577.864	6827643.442	154.894	558577.888	6827643.439	154.882
4hr B	558577.885	6827643.441	154.864	558577.879	6827643.438	154.878	558577.872	6827643.442	154.870	558577.891	6827643.442	154.869
6hr B	558577.886	6827643.440	154.858	558577.883	6827643.437	154.870	558577.875	6827643.442	154.863	558577.891	6827643.439	154.869
8hr B	558577.887	6827643.440	154.854	558577.884	6827643.437	154.868	558577.883	6827643.438	154.859	558577.896	6827643.435	154.867
12hr B	558577.888	6827643.440	154.848	558577.884	6827643.437	154.857	558577.883	6827643.442	154.857	558577.896	6827643.438	154.865
24hr B	558577.886	6827643.441	154.854	558577.886	6827643.436	154.860	558577.883	6827643.438	154.864	558577.899	6827643.438	154.862
	E	N	h	E	N	h	E	N	h	E	N	h
1hr C	558577.879	6827643.439	154.875	*			558577.869	6827643.442	154.872	558577.907	6827643.438	154.864
2hr C	558577.887	6827643.442	154.871	558577.883	6827643.441	154.871	558577.877	6827643.442	154.870	558577.918	6827643.438	154.858
4hr C	558577.884	6827643.439	154.874	558577.881	6827643.439	154.874	558577.880	6827643.442	154.874	558577.905	6827643.435	154.863
6hr C	558577.884	6827643.441	154.879	558577.880	6827643.438	154.877	558577.875	6827643.442	154.879	558577.896	6827643.435	154.870
8hr C	558577.885	6827643.441	154.878	558577.881	6827643.439	154.880	558577.877	6827643.442	154.878	558577.899	6827643.435	154.867
12hr C	558577.887	6827643.440	154.867	558577.883	6827643.438	154.874	558577.886	6827643.442	154.865	558577.889	6827643.435	154.869
24hr C	558577.887	6827643.440	154.871	558577.882	6827643.438	154.875	558577.886	6827643.442	154.864	558577.901	6827643.435	154.865

Table B2 Meerschaum Trig Station Coordinates by Observation Length

	AUSPOS			OPUS			CSRS-PPP			MAGIC-GNSS		
	E	N	h	E	N	h	E	N	h	E	N	h
1hr A	541326.829	6799205.946	207.840	*			541326.818	6799205.943	207.844	541326.840	6799205.946	207.835
2hr A	541326.827	6799205.945	207.859	541326.820	6799205.938	207.860	541326.813	6799205.943	207.869	541326.837	6799205.947	207.850
4hr A	541326.830	6799205.947	207.838	541326.827	6799205.942	207.836	541326.821	6799205.943	207.851	541326.840	6799205.943	207.830
6hr A	541326.832	6799205.947	207.849	541326.830	6799205.944	207.844	541326.826	6799205.943	207.849	541326.843	6799205.940	207.827
8hr A	541326.833	6799205.946	207.846	541326.830	6799205.942	207.843	541326.832	6799205.943	207.841	541326.840	6799205.940	207.828
12hr A	541326.833	6799205.947	207.842	541326.830	6799205.941	207.848	541326.837	6799205.943	207.835	541326.840	6799205.940	207.843
24hr A	541326.833	6799205.947	207.847	541326.830	6799205.941	207.853	541326.837	6799205.940	207.843	541326.840	6799205.940	207.845
	E	N	h	E	N	h	E	N	h	E	N	h
1hr B	541326.831	6799205.937	207.864				541326.818	6799205.947	207.854	541326.856	6799205.950	207.824
2hr B	541326.834	6799205.943	207.850	541326.831	6799205.942	207.855	541326.834	6799205.943	207.841	541326.859	6799205.946	207.824
4hr B	541326.836	6799205.941	207.841	541326.831	6799205.939	207.852	541326.832	6799205.943	207.837	541326.840	6799205.943	207.842
6hr B	541326.836	6799205.942	207.838	541326.833	6799205.935	207.856	541326.837	6799205.943	207.838	541326.848	6799205.940	207.847
8hr B	541326.838	6799205.943	207.837	541326.833	6799205.939	207.856	541326.840	6799205.943	207.838	541326.851	6799205.940	207.852
12hr B	541326.837	6799205.944	207.835	541326.833	6799205.939	207.856	541326.837	6799205.943	207.842	541326.851	6799205.940	207.853
24hr B	541326.836	6799205.945	207.846	541326.840	6799205.939	207.858	541326.837	6799205.943	207.855	541326.851	6799205.940	207.851
	E	N	h	E	N	h	E	N	h	E	N	h
1hr C	541326.838	6799205.948	207.831				541326.826	6799205.946	207.838	541326.867	6799205.940	207.827
2hr C	541326.836	6799205.947	207.843	541326.836	6799205.944	207.846	541326.832	6799205.946	207.848	541326.848	6799205.940	207.841
4hr C	541326.834	6799205.947	207.846	541326.830	6799205.944	207.852	541326.832	6799205.946	207.851	541326.851	6799205.940	207.847
6hr C	541326.834	6799205.947	207.849	541326.831	6799205.945	207.855	541326.826	6799205.946	207.859	541326.848	6799205.937	207.848
8hr C	541326.834	6799205.947	207.846	541326.832	6799205.944	207.850	541326.832	6799205.946	207.854	541326.848	6799205.937	207.848
12hr C	541326.834	6799205.947	207.844	541326.830	6799205.943	207.850	541326.834	6799205.943	207.842	541326.848	6799205.937	207.853
24hr C	541326.834	6799205.947	207.849	541326.835	6799205.942	207.848	541326.832	6799205.943	207.841	541326.851	6799205.940	207.845

* Opus will not process files shorter than 2 hours, one of the two hour files at Hayter Trig contained insufficient data to enable processing.

Appendix C 3hr Residuals

Table C1 3hr GNSS Residuals – Hayter Trig Station

	AUSPOS			OPUS			CSRS			Magic		
	ΔE	ΔN	Δh	ΔE	ΔN	Δh	ΔE	ΔN	Δh	ΔE	ΔN	Δh
0-3-A	0.000	0.006	0.017	-0.008	-0.005	0.018	-0.010	0.003	-0.008	-0.002	0.003	0.015
3-6-A	-0.001	0.003	0.004	-0.005	0.001	0.017	-0.010	0.003	0.012	0.001	-0.007	0.021
6-9-A	-0.001	0.005	0.020	-0.003	-0.003	0.017	-0.005	0.006	0.030	0.001	0.006	0.038
9-12-A	0.001	0.002	-0.011	0.023	-0.005	0.043	0.014	-0.010	-0.016	0.025	-0.007	-0.006
12-15-A	0.006	0.011	-0.013	0.003	0.003	0.008	0.001	0.002	0.027	0.001	0.003	0.012
15-18-A	0.001	0.003	0.003	-0.005	-0.004	-0.040	0.001	0.002	-0.006	0.017	-0.001	-0.076
18-21-A	-0.003	0.005	-0.003	-0.008	-0.002	0.014	-0.013	0.009	0.021	0.009	0.006	0.009
21-24-A	0.005	0.005	-0.009	0.018	-0.007	0.076	-0.024	0.024	-0.027	0.011	0.006	0.017
0-3-B	-0.007	0.001	0.019	-0.008	-0.001	0.022	-0.014	0.004	0.019	0.007	0.000	0.012
3-6-B	-0.001	0.003	-0.011	0.003	-0.006	-0.032	-0.006	0.004	-0.009	0.005	0.001	-0.001
6-9-B	0.000	0.001	-0.032	-0.005	-0.001	-0.003	-0.003	0.004	-0.031	0.005	0.004	0.000
9-12-B	-0.001	0.004	-0.014	-0.008	0.003	-0.021	-0.003	-0.003	0.006	0.013	0.000	0.010
12-15-B	-0.003	0.003	-0.007	-0.020	-0.007	-0.002	-0.017	0.007	0.005	0.018	0.000	-0.025
15-18-B	-0.003	0.004	0.009	-0.006	-0.003	0.011	-0.003	0.007	-0.003	0.005	0.004	0.009
18-21-B	-0.002	0.000	-0.004	-0.010	-0.005	-0.001	0.010	0.010	-0.007	0.016	0.000	-0.017
21-24-B	-0.007	0.007	-0.005	-0.011	-0.004	-0.017	0.029	0.006	0.019	0.007	-0.003	0.022
0-3-C	-0.002	0.001	0.004	-0.007	-0.002	0.007	-0.009	0.000	0.011	0.018	-0.004	-0.004
3-6-C	-0.004	0.003	0.012	-0.006	0.002	0.014	-0.020	0.000	0.023	0.007	-0.007	0.005
6-9-C	0.000	0.002	0.001	-0.006	-0.001	-0.001	-0.001	0.009	-0.002	0.013	-0.007	-0.007
9-12-C	0.001	0.001	-0.002	0.034	0.009	0.055	-0.001	-0.004	-0.016	0.037	-0.004	0.014
12-15-C	0.000	0.004	-0.005	-0.011	0.002	0.000	-0.009	0.006	0.006	-0.001	0.006	-0.003
15-18-C	-0.004	0.001	0.008	-0.007	0.001	0.012	-0.022	0.006	0.019	0.010	0.003	-0.018
18-21-C	-0.003	0.002	0.010	-0.007	-0.004	-0.002	-0.003	0.003	0.004	0.018	-0.004	-0.008
21-24-C	-0.002	0.001	-0.003	-0.011	-0.003	0.008	-0.014	0.006	-0.046	0.018	-0.004	-0.016

Table C2 3hr GNSS Residuals – Meerschaum Trig Station

	AUSPOS			OPUS			CSRS			Magic		
	ΔE	ΔN	Δh	ΔE	ΔN	Δh	ΔE	ΔN	Δh	ΔE	ΔN	Δh
0-3-A	-0.005	0.012	0.001	-0.008	-0.003	0.015	-0.019	0.001	0.018	0.005	0.004	-0.012
3-6-A	-0.001	0.005	-0.004	-0.002	-0.002	0.005	-0.001	0.001	-0.005	0.013	0.001	-0.017
6-9-A	0.000	0.005	-0.012	-0.009	-0.002	-0.013	0.005	0.004	-0.013	-0.001	0.008	0.013
9-12-A	-0.001	0.007	-0.010	-0.008	0.002	0.002	-0.003	0.001	-0.018	0.010	-0.005	0.016
12-15-A	0.000	0.006	-0.003	-0.001	0.004	0.003	-0.003	0.004	0.020	0.013	0.001	0.002
15-18-A	0.000	0.006	0.006	-0.003	-0.001	0.021	-0.006	0.011	0.008	0.018	-0.002	-0.020
18-21-A	0.000	0.005	0.006	-0.007	0.003	0.016	0.002	0.001	-0.016	0.013	-0.005	0.009
21-24-A	-0.002	0.004	-0.011	-0.001	-0.002	0.003	-0.028	-0.008	-0.001	-0.025	-0.020	-0.060
0-3-B	-0.006	0.001	-0.008	-0.009	-0.005	0.009	-0.012	0.001	-0.016	0.002	0.004	-0.016
3-6-B	-0.008	-0.001	-0.014	-0.008	-0.003	-0.014	-0.004	0.001	-0.019	0.010	-0.002	0.003
6-9-B	0.000	0.003	-0.019	-0.010	-0.002	0.020	-0.007	0.001	-0.021	0.012	-0.005	-0.015
9-12-B	-0.006	0.005	-0.005	0.025	-0.004	0.075	0.021	-0.002	0.015	0.021	0.007	0.017
12-15-B	-0.006	0.004	0.013	-0.007	0.003	0.003	-0.009	0.008	0.006	0.018	0.008	-0.021
15-18-B	-0.005	0.004	-0.007	-0.011	-0.005	0.027	-0.009	0.011	-0.017	0.010	0.001	-0.019
18-21-B	-0.007	0.000	-0.003	-0.010	-0.004	0.007	0.002	0.001	-0.004	0.015	0.001	-0.004
21-24-B	-0.011	0.002	0.004	-0.013	-0.003	0.014	0.015	-0.002	0.016	-0.009	-0.011	0.020
0-3-C	-0.004	0.004	0.007	-0.006	0.003	0.008	-0.006	0.003	0.012	0.015	-0.003	-0.002
3-6-C	-0.003	0.005	0.004	-0.008	0.003	0.010	-0.014	0.000	0.014	0.010	-0.006	-0.010
6-9-C	-0.003	0.004	0.001	-0.009	0.000	-0.013	-0.004	0.007	0.004	0.015	-0.003	0.020
9-12-C	-0.006	0.000	0.002	-0.011	-0.003	0.008	-0.017	0.000	-0.016	0.021	-0.006	0.016
12-15-C	-0.003	0.004	0.005	-0.007	0.003	0.009	-0.006	0.007	0.003	0.005	0.003	-0.007
15-18-C	-0.004	0.002	0.007	-0.006	0.003	0.004	-0.012	0.003	0.008	0.024	0.000	-0.009
18-21-C	-0.002	0.004	0.003	-0.007	0.000	0.010	-0.001	0.000	-0.018	0.018	0.000	-0.020
21-24-C	-0.006	0.007	0.000	-0.007	-0.002	-0.009	-0.017	0.003	-0.002	0.010	0.000	0.015

Table C2 3hr GPS Residuals

	GPS Solution	CSRS-PPP			MAGIC-GNSS		
		ΔE	ΔN	Δh	ΔE	ΔN	Δh
Hay	0-3hr A	-0.016	0.013	-0.002	-0.011	0.010	0.031
	0-3hr B	-0.011	0.004	0.017	-0.005	0.004	0.018
	0-3hr C	-0.014	0.009	0.011	0.000	-0.001	0.001
	3-6hr A	-0.013	0.006	0.003	0.011	-0.003	-0.015
	3-6hr B	0.011	0.000	-0.051	0.008	0.000	-0.032
	3-6hr C	-0.022	0.006	0.023	0.005	-0.013	0.005
	6-9hr A	-0.027	0.013	0.021	-0.016	0.003	0.026
	6-9hr B	-0.005	0.007	-0.038	0.000	0.007	-0.024
	6-9hr B	-0.016	0.009	-0.025	-0.005	-0.007	-0.040
	9-12hr A	0.006	0.006	-0.019	0.008	-0.003	-0.018
	9-12hr B	-0.005	0.000	-0.001	0.022	0.003	-0.001
	9-12hr C	0.019	0.005	-0.019	0.038	-0.004	0.000
	12-15hr A	-0.011	0.010	0.010	-0.005	-0.003	0.021
	12-15hr B	-0.019	0.010	-0.002	-0.005	0.000	-0.027
	12-15hr C	-0.008	0.009	0.000	0.000	-0.001	-0.001
	15-18hr A	-0.016	0.013	-0.001	0.044	-0.003	0.029
	15-18hr B	-0.005	0.010	-0.010	0.019	0.000	-0.028
	15-18hr C	-0.033	0.012	0.032	0.003	0.003	-0.024
	18-21hr A	-0.024	0.010	0.008	-0.014	-0.009	-0.031
	18-21hr B	0.008	0.013	-0.014	0.008	0.007	-0.022
	18-21hr C	-0.008	-0.001	-0.024	0.019	-0.007	-0.025
	21-24hr A	0.008	0.037	0.012	-0.003	0.010	0.020
	21-24hr B	0.027	0.009	0.012	-0.008	-0.003	0.004
	21-24hr C	-0.019	0.006	-0.044	-0.022	-0.016	-0.022
Meer	0-3hr A	-0.019	0.001	0.018	0.010	0.004	-0.026
	0-3hr B	-0.012	0.001	-0.016	0.004	0.008	-0.010
	0-3hr C	-0.006	0.003	0.012	-0.001	-0.003	-0.002
	3-6hr A	-0.001	0.001	-0.005	0.016	-0.011	-0.022
	3-6hr B	-0.004	0.001	0.081	0.010	-0.011	-0.018
	3-6hr C	-0.014	0.000	0.014	0.013	-0.018	-0.017
	6-9hr A	0.005	0.004	-0.013	0.005	-0.002	-0.021
	6-9hr B	-0.007	0.001	-0.021	0.029	-0.002	-0.009
	6-9hr B	-0.004	0.007	0.004	0.005	-0.006	-0.007
	9-12hr A	-0.003	0.001	-0.018	0.024	-0.008	0.031
	9-12hr B	0.021	-0.002	0.015	0.031	0.001	0.014
	9-12hr C	-0.017	0.000	-0.016	-0.004	-0.006	0.006
	12-15hr A	-0.003	0.004	0.020	0.021	0.001	-0.010
	12-15hr B	-0.009	0.008	0.006	0.034	-0.002	0.009
	12-15hr C	-0.006	0.007	0.003	0.013	0.000	-0.018
	15-18hr A	-0.006	0.011	0.008	0.027	-0.008	-0.031
	15-18hr B	-0.009	0.011	-0.017	0.012	-0.002	-0.017
	15-18hr C	-0.012	0.003	0.008	0.029	-0.003	-0.013
	18-21hr A	0.002	0.001	-0.016	0.024	0.001	0.030
	18-21hr B	0.002	0.001	-0.004	0.026	0.004	0.011
	18-21hr C	-0.001	0.000	-0.018	0.021	0.000	-0.013
	21-24hr A	-0.028	-0.008	-0.001	-0.044	-0.017	-0.029
	21-24hr B	0.015	-0.002	0.016	-0.020	-0.008	0.008
	21-24hr C	-0.017	0.003	-0.002	0.037	0.003	-0.008

Appendix D RINEX File Example

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     2.11           OBSERVATION DATA    M                RINEX VERSION / TYPE
LEICA GEO OFFICE 8.3                  7-9-14 16:36        PGM / RUN BY / DATE
                                     OBSERVER / AGENCY
0567081714194394                              MARKER NAME
0567081714194394                              MARKER NUMBER
2870567             LEICA GS14          5.02              REC # / TYPE / VERS
                LEIGS14                          ANT # / TYPE
 -5016178.7285  2490100.9687 -3042624.3472                 APPROX POSITION XYZ
       0.1900        0.0000        0.0000               ANTENNA: DELTA H/E/N
L1PhaOff:   0.0887  L2PhaOff:   0.0887                 COMMENT
     1     1                                  WAVELENGTH FACT L1/2
     8    C1    L1    D1    S1    P2    L2    D2    S2      # / TYPES OF OBSERV
  2014     8    16    12     0    0.0000000     GPS         TIME OF FIRST OBS
  2014     8    16    12    59    45.0000000     GPS         TIME OF LAST OBS
    16                                        LEAP SECONDS
    18                                        # OF SATELLITES
        C1    L1    D1    S1    P2    L2    D2    S2      COMMENT
   G 1   103   103   103   103   103   103   103   103      PRN / # OF OBS
   G 2   176   176   176   176   175   175   175   175      PRN / # OF OBS
   G 4   240   240   240   240   240   240   240   240      PRN / # OF OBS
   G 6   240   240   240   240   240   240   240   240      PRN / # OF OBS
   G 8    71    71    71    71    71    71    71    71      PRN / # OF OBS
   G15   240   240   240   240   240   240   240   240      PRN / # OF OBS
   G17   240   240   240   240   240   240   240   240      PRN / # OF OBS
   G24   225   225   225   225   224   224   224   224      PRN / # OF OBS
   G26   240   240   240   240   240   240   240   240      PRN / # OF OBS
   G28   240   240   240   240   240   240   240   240      PRN / # OF OBS
   G30   240   240   240   240   240   240   240   240      PRN / # OF OBS
   R 9    74    74    74    74    73    73    73    73      PRN / # OF OBS
   R10   240   240   240   240   240   240   240   240      PRN / # OF OBS
   R11   240   240   240   240   240   240   240   240      PRN / # OF OBS
   R12   119   119   119   119   119   119   119   119      PRN / # OF OBS
   R20   240   240   240   240   240   240   240   240      PRN / # OF OBS
   R21   240   240   240   240   240   240   240   240      PRN / # OF OBS
   R22   240   240   240   240   240   240   240   240      PRN / # OF OBS
                                     END OF HEADER
 14 08 16 12 00  0.0000000  0 15G 4G15G 6G 1G17G 8G30G28G26R 9R10R11
                          R21R22R20
  21952385.580   115360569.98509      299.473         50.250    21952380.880
  89891331.26047       233.355          42.150
  23311624.740   122503415.11508      148.594         47.200    23311619.000
  95457186.91545       115.787          37.800
  22771941.200   119667359.44808     3186.730         46.850    22771939.160
  93247280.63046      2483.166          39.200
  24069877.960   126488070.47307    -1961.831         43.600    24069875.620
  98562146.37445     -1528.699          37.150
  20158370.060   105932994.96009     -937.052         51.800    20158364.000
  82545182.31249      -730.171          48.800
  24449664.440   128483897.34407    -3031.047         43.900    24449660.500
 100117338.86045     -2361.854          37.000
  22235982.360   116850928.66209    -2591.029         49.200    22235979.480
  91052691.14547     -2018.984          41.600
  21472624.720   112839461.18809    -1519.279         49.700    21472618.080
  87926853.20946     -1183.854          40.950
  21990456.360   115560640.77509    -1157.660         49.100    21990451.480
  90047244.53446      -902.074          40.200
  22907358.480   122324050.92007    -2967.669         41.550    22907356.460
  95140939.41504     -2308.189          33.100
```

Appendix E Leica Viva GNSS GS14 Specification

Leica Viva GNSS GS14 receiver
Datasheet

Proven GNSS Technology

Built on years of knowledge and experience, the Leica GS14 delivers the hallmarks of Leica GNSS – reliability and accuracy.

- Leica SmartCheck – RTK data-processing to guarantee correct results
- Leica SmartTrack – best measurement data quality in all environments
- Leica xRTK – delivers more positions in difficult environments

Flexibility

The Leica GS14 is designed to suit any measuring task.

- Integrated mobile communications and UHF radio modems (receive and transmit)
- Fully scalable sensor allows you to buy only what you need today and upgrade with additional functionality as you need it
- Integrated web server

Rugged

The Leica GS14 is built for the most demanding environments.

- IP68 protection against dust and continuous immersion
- Built for extreme temperatures of –40°C to +65°C
- Integrated mobile communication intenna technology to avoid breaking, losing or forgetting antenna

- when it has to be **right**

Leica Geosystems

Technical Specifications

Leica GS14 GNSS Receiver	Leica GS14 Single Frequency	Leica GS14 Performance	Leica GS14 Professional
Supported GNSS systems			
GPS L2	○	●	●
GLONASS	○	○	●
Galileo	○	○	●
BeiDou	○	○	○
RTK Performance			
DGPS/ RTCM	○	●	●
RTK unlimited	○	●	●
Network RTK	○	●	●
Position Update & Data Recording			
5 Hz positioning	●	●	●
20 Hz positioning	○	●	●
Raw data logging	●	●	●
RINEX logging	○	○	●
NMEA out	○	○	●
Additional Features			
RTK reference station functionality	○	●	●
Modem (choice of 2G or 3.75G)	●	●	●
UHF radio modem (receive and transmit)	○	○	○
	● = Standard	○ = Optional	

GNSS Performance	GNSS technology	Leica patented SmartTrack technology: • Advanced measurement engine • Jamming resistant measurements • High precision pulse aperture multipath correlator for pseudorange measurements • Excellent low elevation tracking • Very low noise GNSS carrier phase measurements with <0.5 mm precision • Minimum acquisition time
	No. of channels	120 channels (240 channels)[1]
	Max. simultaneous tracked satellites	Up to 60 Satellites simultaneously on two frequencies
	Satellite signals tracking	• GPS: L1, L2, L2C • GLONASS: L1, L2 • Galileo, QZSS[2] • BeiDou[1] • SBAS: WAAS, EGNOS, GAGAN, MSAS
	Reacquisition time	< 1 sec
	Position latency	Typically 0.02 sec
Measurement Performance & Accuracy	**Accuracy (rms) code differential with DGPS / RTCM[3]**	
	DGPS / RTCM	Typically 25 cm
	Accuracy (rms) with Real-time-Kinematic (RTK)[3]	
	Standard of compliance	Compliance with ISO17 123-8
	Single Baseline (< 30 km)	Horizontal: 8 mm + 1 ppm Vertical: 15 mm + 1 ppm
	Network RTK	Horizontal: 8 mm + 0.5 ppm Vertical: 15 mm + 0.5 ppm
	Accuracy (rms) with post processing[3]	
	Static (phase) with long observations	Horizontal: 3 mm + 0.1 ppm Vertical: 3.5 mm + 0.4 ppm
	Static and rapid static (phase)	Horizontal: 3 mm + 0.5 ppm Vertical: 5 mm + 0.5 ppm
	Kinematic (phase)	Horizontal: 8 mm + 1 ppm Vertical: 15 mm + 1 ppm
	On-the-fly (OTF) initialisation	
	RTK technology	Leica SmartCheck technology
	Reliability	Better than 99.99%[3]
	Time for initialisation	Typically 4 sec[4]
	OTF range	Up to 70 km[3]
	Network RTK	
	Supported RTK network solutions	VRS, FKP, iMAX
	Supported RTK network standards	MAC (Master Auxiliary Concept) approved by RTCM SC 104

[1] Future upgrade possibility to 240 channels including GPS L5 and BeiDou.
[2] Support of QZSS is incorporated and will be provided through firmware upgrade.
[3] Measurement precision, accuracy and reliability are dependent upon various factors including number of satellites, geometry obstructions, observation time, ephemeris accuracy, ionospheric conditions, multipath etc. Figures quoted assume normal to favourable conditions. Times required are dependent upon various factors including number of satellites, geometry, ionospheric conditions, multipath etc. GPS and GLONASS can increase performance and accuracy by up to 30% relative to GPS only.
[4] Might vary due to atmospheric conditions, signal multipath, obstructions, signal geometry and number of tracked signals.

Leica GS14 GNSS Receiver

Hardware	**Weight & Dimensions**	
	Weight (GS14)	0.93 kg
	Weight	2.90 kg standard RTK rover including controller, batteries, pole and bracket
	Dimension (GS14) (diameter x height)	190 mm x 90 mm
	Environmental Specifications	
	Temperature, operating	–40° C to +65° C, compliance with ISO9022-10-08, ISO9022-11-special, MIL STD 810G Method 502.5 II, MIL STD 810G Method 501.5 II
	Temperature, storage	–40° C to +80° C, compliance with ISO9022-10-08, ISO9022-11-special, MIL STD 810G Method 502.5 I, MIL STD 810G Method 501.5 I
	Humidity	100%, compliance with ISO9022-13-06, ISO9022-12-06 and MIL STD 810G Method 507.5 I
	Proof against: water, sand and dust	IP68 according IEC60529 and MIL STD 810G Method 506.5 I, MIL STD 810G Method 510.5 I and MIL STD 810G Method 512.5 I Protected against blowing rain and dust Protected against temporary submersion into water (max. depth 1,4 m)
	Vibration	Withstands strong vibration during operating, compliance with ISO9022-36-08 and MIL STD 810G Method 514.6 Cat.24
	Drops	Withstands 1.0 m drop onto hard surfaces
	Functional shock	40 g / 15 to 23 msec, compliance with MIL STD 810G Method 516.6 I No loss of lock to satellite signal when used on a pole set-up and submitted to pole bumps up to 100 mm
	Topple over	Withstands topple over from a 2 m survey pole onto hard surfaces
	Power & Electrical	
	Supply voltage	Nominal 12 V DC Range 10.5 – 28 V DC
	Power consumption	Typically: 2.0 W, 270 mA UHF transmit: 3.3 W, 270 mA
	Internal power supply	Recharge & removable Li-Ion battery, 2.6 Ah / 7.4 V, 1 battery fit into receiver
	Internal power supply, operation time	• 10.00 h static observations[1] • 7.00 h receiving RTK data with internal UHF radio[2] • 5.00 h transmitting RTK data with internal UHF radio[2] • 6.00 h receiving / transmitting RTK data with internal modem[2]
	External power supply	Rechargeable external NiMh battery 9 Ah / 12 V
	Certifications	Compliance to: FCC, CE, PTCRB Local and operator specific approvals (as IC Canada, C-Tick Australia, Japan, China, AT&T)
Memory & Data Recording	**Memory**	
	Memory medium	Removable microSD Card: 1 GB
	Data capacity	1 GB is typically sufficient for about GPS & GLONASS (8+4 satellites) 280 days raw data logging at 15 s rate
	Data Recording	
	Type of data	Onboard recording of: • Leica GNSS raw data • RINEX data
	Recording rate	Up to 20 Hz
User Interface	Buttons	• ON / OFF button • Function button
	Button functionality	Function button: • Easy switch between Rover / Base mode • Easy "Here" positioning functionality
	Led status indicator	*Bluetooth*®, position, RTK Rover status, RTK Base status, data logging, internal power status, external power status
	Additional user interface	Additional web interface functionality provides full status indicator and configuration options
Communications	Communication ports	1 x USB / RS232 Lemo 1 x *Bluetooth*® port, *Bluetooth*® v2.00+ EDR, class 2
	Built-in Data Links	
	Radio modem	• Fully integrated, fully sealed receive and transmit radios • SATEL, Pacific Crest and TrimTalk support • 403 – 473 MHz bandwidth • Output power 1W max.
	UHF antenna options	• External UHF antenna connector (Type QN)
	GSM / UMTS phone modem	• Fully integrated, fully sealed 3.75G phone modem • Quad-Band GSM / GPRS: 850 / 900 / 1800 / 1900 MHz • Penta-Band UMTS: 800 / 850 / 900 / 1900 / 2100 MHz • DynDNS service support – Base station supports up to 10 rovers via TCP/IP
	GSM / UMTS antenna	• Integrated GSM / UMTS antenna
	External Data Links	
	Radio modems	Support of any suitable UHF / VHF radio
	GSM / UMTS / CDMA phone modems	Support of any suitable GSM / GPRS / UMTS / CDMA modem
	Landline phone modems	Support of any suitable landline phone modem
	Communication Protocols	
	Real-time data formats for data transmission and reception	Leica proprietary formats (Leica, Leica 4G) CMR, CMR+
	Real-time data formats according RTCM standard for data transmission and reception	RTCM 2.1, RTCM 2.3, RTCM 3.0, RTCM 3.1, RTCM 3.2 MSM Full support of RTCM 3 Transformation Message
	NMEA output	NMEA 0183 V 4.00 and Leica proprietary

[1] Might vary with temperatures, age of battery, transmit power of data link device.

Scan with your iPhone or iPad to get the Leica Viva GNSS App or visit www.leica-geosystems.com/viva-gnss

Whether you want to stake-out an object on a construction site or you need accurate measurements of a tunnel or a bridge; whether you want to determine the area of a parcel of land or need the position of a power pole or to capture objects for as-built maps – you need reliable and precise data.

Leica Viva combines a wide range of innovative products designed to meet the daily challenges for all positioning tasks. The simple yet powerful and versatile Leica Viva hardware and software innovations are redefining state-of-the-art technology to deliver maximum performance and productivity. Leica Viva gives you the inspiration to make your ambitious visions come true.

When it has to be right.

Swiss Technology

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Leica Viva
Overview brochure

Leica SmartWorx Viva
Product brochure

Leica Viva LGO
Product brochure

Leica Viva SmartPole
Product brochure

Leica Geosystems AG
Heerbrugg, Switzerland
www.leica-geosystems.com

- when it has to be right

Appendix F SCIMS Survey Mark Reports

SCIMS SURVEY MARK REPORT AS AT: 8-JUL-2014

Your Reference: Dans Uni Search Number: 200982

MARK NAME STATUS	COORDINATES AND HEIGHTS				CLASS	ORDER	PU	SOURCE	CSF CONVERGENCE AUSGEOID09
TS 7270	MGA	558577.506	6827642.317	56	A	1	n/a	229847	0.999618
HAYTER [P]	GDA94	-28° 40' 37.51731"	153° 35' 58.38841"						0° 17' 15.78"
	AHD71	116.698			B	2	n/a	229847	38.240
TS 6600	MGA	541326.531	6799204.769	56	2A	0	0.08	229793	0.999588
MEERSCHAUM [P]	GDA94	-28° 56' 03.95411"	153° 25' 26.50055"						0° 12' 18.54"
	AHD71	170.558			LA	L1	n/a	229331	37.380

Map Legend

SCIMS Mark Types (Colour codes refer to the assigned accuracy "Class")

SS	PM	TS	CR	MM	CP	GB	
							Established GDA & Accurate AHD
							Established GDA Only
							Accurate AHD Only
							Unknown or Less Accurate GDA & AHD

Established GDA coordinates are assigned accuracy class 2A, A, B or C

Accurate AHD heights are assigned accuracy class L2A, LA, LB, LC, LD, 2A, A or B

Mark Status *

F Found Intact

N Not Found

D Destroyed

S Subsidence Area

U Uncertain

R Restricted Access

* Where available, the Mark Status is appended to the Mark Number in the map

SCIMS SURVEY MARK SUMMARY REPORT AS AT: 28-MAY-2014

Your Reference: Search Number:

SURVEY MARK		
Mark	Name	Alias
TS 7270	HAYTER [P]	n/a

Status	Date	Comments
	n/a	n/a

Location	Monument	Date Placed	Placed By
GROUND LEVEL	CONC PILLAR	29-APR-1988	LAND & PROPERTY INFORMATION -

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
A	1	n/a	n/a	11-MAY-2005

Source	Type	Method	Date issued	Issued By
229847	ADJUSTMENT	GEOLAB	12-AUG-2004	GRAEME STEWART

Previous Reference	Location	File Number
n/a	BALLINA - (LGA)	n/a

Comments
BALLINA SHIRE UPDATE ....

MGA Combined Scale Factor	MGA Convergence
0.999618	0° 17' 15.78"

AusGeoid09
38.240

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
B	2	n/a	n/a	11-MAY-2005

Source	Type	Method	Date issued	Issued By
229847	ADJUSTMENT	GEOLAB	12-AUG-2004	GRAEME STEWART

Previous Reference	Location	File Number
n/a	BALLINA - (LGA)	n/a

Comments
BALLINA SHIRE UPDATE ....

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
7270-3	GI PIPE IN SOIL	271° 37' 25.7"	5.011	-1.288

Alias	Status
n/a	

Date	Comments
n/a	n/a

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GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
A	1	n/a	n/a	11-MAY-2005

Source	Type	Method	Date issued	Issued By
229847	ADJUSTMENT	GEOLAB	12-AUG-2004	GRAEME STEWART

Previous Reference	Location	File Number
n/a	BALLINA - (LGA)	n/a

Comments
BALLINA SHIRE UPDATE ....

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
D	4	n/a	n/a	23-SEP-1997

Source	Type	Method	Date issued	Issued By
201647	HEIGHTING	UNKNOWN	23-SEP-1997	n/a

Previous Reference	Location	File Number
97187	n/a	n/a

Comments
n/a

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
7270-2	CU NAIL IN CONC	335° 31' 01.7"	5.656	-1.452

Alias	Status
n/a	

Date	Comments
n/a	n/a

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
A	1	n/a	n/a	11-MAY-2005

Source	Type	Method	Date issued	Issued By
229847	ADJUSTMENT	GEOLAB	12-AUG-2004	GRAEME STEWART

Previous Reference	Location	File Number
n/a	BALLINA - (LGA)	n/a

Comments
BALLINA SHIRE UPDATE ....

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
D	4	n/a	n/a	23-SEP-1997

Source	Type	Method	Date issued	Issued By
201647	HEIGHTING	UNKNOWN	23-SEP-1997	n/a

Previous Reference	Location	File Number
97187	n/a	n/a

Comments
n/a

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
7270-1	S/S PIN IN CONC	55° 08' 19.9"	4.764	-1.691

Alias	Status
n/a	

Date	Comments
n/a	n/a

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
A	1	n/a	n/a	11-MAY-2005

Source	Type	Method	Date issued	Issued By
229847	ADJUSTMENT	GEOLAB	12-AUG-2004	GRAEME STEWART

Previous Reference	Location	File Number
n/a	BALLINA - (LGA)	n/a

Comments
BALLINA SHIRE UPDATE ....

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
D	4	n/a	n/a	23-SEP-1997

Source	Type	Method	Date issued	Issued By
201647	HEIGHTING	UNKNOWN	23-SEP-1997	n/a

Previous Reference	Location	File Number
97187	n/a	n/a

Comments
n/a

TRIG STATION

Trig Type	55/11	Station Originally Established By
PILLAR	1414	LAND & PROPERTY INFORMATION - BATHURST

GNB Approved	Reference	Reserve No.	Reserve Name
15-SEP-1989	72335	n/a	n/a

BEACON

Description	Date Placed	Placed By
MAST AND VANES	29-APR-1988	LAND & PROPERTY INFORMATION - BATHURST

Vane Top Height	Vane Diameter
1.44	0.75

VISITATION LOG

Date	Organisation	Comments
3-MAR-2009	DEPARTMENT OF LANDS - LISMORE	STATION OCCUPIED FOR GPS CONTROL SURVEY, BYRON SHIRE
15-NOV-2007	DEPARTMENT OF LANDS - LISMORE	STATION OCCUPIED FOR LOCAL GPS SURVEY
15-JAN-2007	DEPARTMENT OF LANDS - LISMORE	GPS OCCUPATION (24 HOUR SESSION) FOR AUSPOS. PAINT VANES
3-JAN-2007	DEPARTMENT OF LANDS - LISMORE	GPS OCCUPATION (24 HOUR SESSION) FOR AUSPOS

VISITATION LOG

Date	Organisation	Comments
22-FEB-2005	DEPARTMENT OF LANDS - LISMORE	STATION OCCUPIED. REPLACE 2 VANE STRAPS, 2 CLAMPS, PAINT MAST AND VANES.
17-DEC-2004	DEPARTMENT OF LANDS - LISMORE	RECONNAISANCE FOR ACCESS
26-APR-2002	LAND & PROPERTY INFORMATION - BATHURST	TRIG SIGHTED, MAST AND VANES ON PILLAR ARE INTACT.
16-JAN-1998	DEPARTMENT OF LANDS - LISMORE	FIT NEW MAST AND VANES TO PILLAR.
13-MAR-1997	DEPARTMENT OF LANDS - LISMORE	STATION OCCUPIED FOR GPS CONTROL SURVEY, COOPERS SHOOT
10-FEB-1997	DEPARTMENT OF LANDS - LISMORE	RECCE AND SKYPLOT FOR GPS SURVEY
2-MAY-1988	LAND & PROPERTY INFORMATION - BATHURST	S/S PIN IN CONC, CU NAIL IN CONC PLACED, GI PIPE IN SOIL FOUND & CONNECTED. ACCESS SUPPLIED

SCIMS SURVEY MARK SUMMARY REPORT AS AT: 28-MAY-2014

Your Reference: Search Number:

SURVEY MARK

Mark	Name	Alias
TS 6600	MEERSCHAUM [P]	n/a

Status	Date	Comments
	n/a	n/a

Location	Monument	Date Placed	Placed By
GROUND LEVEL	CONC PILLAR	11-NOV-1980	LAND & PROPERTY INFORMATION -

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
2A	0	0.08	n/a	20-MAY-2008

Source	Type	Method	Date issued	Issued By
229793	ADJUSTMENT	NEWGAN	1-JUL-2004	GLENN JONES

Previous Reference	Location	File Number
200035	n/a	T 14377.2

Comments
RE-UPDATE USING QLD 1R1 SPINE SECTION

MGA Combined Scale Factor	MGA Convergence
0.999588	0° 12' 18.54"

AusGeoid09
37.380

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
LA	L1	n/a	n/a	6-JAN-2004

Source	Type	Method	Date issued	Issued By
229331	LEVELLING	LEVADJ	6-JAN-2004	GLENN JONES

Previous Reference	Location	File Number
4158 (SS 6279) 4159 (TS 6600)	MEERSCHAUM	n/a

Comments
SUPERCEDES ORIGINAL SECTION DUE TO RE-CALCULATION OF 202-203 (SSM 6279)

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
6600-8	TOWER	304° 48' 00.9"	216.76	28.29

Alias	Status
n/a	

Date	Comments
n/a	n/a

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GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
2A	0	0.08	n/a	20-MAY-2008

Source	Type	Method	Date issued	Issued By
229793	ADJUSTMENT	NEWGAN	1-JUL-2004	GLENN JONES

Previous Reference	Location	File Number
200035	n/a	T 14377.2

Comments
RE-UPDATE USING QLD 1R1 SPINE SECTION

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
LA	L1	n/a	n/a	6-JAN-2004

Source	Type	Method	Date issued	Issued By
229331	LEVELLING	LEVADJ	6-JAN-2004	GLENN JONES

Previous Reference	Location	File Number
4158 (SS 6279) 4159 (TS 6600)	MEERSCHAUM	n/a

Comments
SUPERCEDES ORIGINAL SECTION DUE TO RE-CALCULATION OF 202-203 (SSM 6279)

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
6600-7	GI PIPE IN SOIL	314° 51' 15.3"	193.036	-5.13

Alias	Status
n/a	

Date	Comments
n/a	n/a

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
2A	0	0.08	n/a	20-MAY-2008

Source	Type	Method	Date issued	Issued By
229793	ADJUSTMENT	NEWGAN	1-JUL-2004	GLENN JONES

Previous Reference	Location	File Number
200035	n/a	T 14377.2

Comments
RE-UPDATE USING QLD 1R1 SPINE SECTION

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
LA	L1	n/a	n/a	6-JAN-2004

Source	Type	Method	Date issued	Issued By
229331	LEVELLING	LEVADJ	6-JAN-2004	GLENN JONES

Previous Reference	Location	File Number
4158 (SS 6279) 4159 (TS 6600)	MEERSCHAUM	n/a

Comments
SUPERCEDES ORIGINAL SECTION DUE TO RE-CALCULATION OF 202-203 (SSM 6279)

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
6600-6	GI PIPE IN SOIL	304° 57' 04.0"	174.236	-4.15

Alias	Status
n/a	

Date	Comments
n/a	n/a

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
2A	0	0.08	n/a	20-MAY-2008

Source	Type	Method	Date issued	Issued By
229793	ADJUSTMENT	NEWGAN	1-JUL-2004	GLENN JONES

Previous Reference	Location	File Number
200035	n/a	T 14377.2

Comments
RE-UPDATE USING QLD 1R1 SPINE SECTION

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
LA	L1	n/a	n/a	6-JAN-2004

Source	Type	Method	Date issued	Issued By
229331	LEVELLING	LEVADJ	6-JAN-2004	GLENN JONES

Previous Reference	Location	File Number
4158 (SS 6279) 4159 (TS 6600)	MEERSCHAUM	n/a

Comments
SUPERCEDES ORIGINAL SECTION DUE TO RE-CALCULATION OF 202-203 (SSM 6279)

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
6600-5	CU NAIL IN CONC	335° 08' 14.4"	4.475	-1.425

Alias	Status
n/a	

Date	Comments
n/a	n/a

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
2A	0	0.08	n/a	20-MAY-2008

Source	Type	Method	Date issued	Issued By
229793	ADJUSTMENT	NEWGAN	1-JUL-2004	GLENN JONES

Previous Reference	Location	File Number
200035	n/a	T 14377.2

Comments
RE-UPDATE USING QLD 1R1 SPINE SECTION

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
LA	L1	n/a	n/a	6-JAN-2004

Source	Type	Method	Date issued	Issued By
229331	LEVELLING	LEVADJ	6-JAN-2004	GLENN JONES

Previous Reference	Location	File Number
4158 (SS 6279) 4159 (TS 6600)	MEERSCHAUM	n/a

Comments
SUPERCEDES ORIGINAL SECTION DUE TO RE-CALCULATION OF 202-203 (SSM 6279)

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
6600-4	SPIKE IN CONC	311° 24' 33.5"	3.236	-1.525

Alias	Status
n/a	

Date	Comments
n/a	n/a

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
2A	0	0.08	n/a	20-MAY-2008

Source	Type	Method	Date issued	Issued By
229793	ADJUSTMENT	NEWGAN	1-JUL-2004	GLENN JONES

Previous Reference	Location	File Number
200035	n/a	T 14377.2

Comments
RE-UPDATE USING QLD 1R1 SPINE SECTION

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
LA	L1	n/a	n/a	6-JAN-2004

Source	Type	Method	Date issued	Issued By
229331	LEVELLING	LEVADJ	6-JAN-2004	GLENN JONES

Previous Reference	Location	File Number
4158 (SS 6279) 4159 (TS 6600)	MEERSCHAUM	n/a

Comments
SUPERCEDES ORIGINAL SECTION DUE TO RE-CALCULATION OF 202-203 (SSM 6279)

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
6600-3	CART CASE (ORIG)	264° 41' 46.0"	3.264	-1.851

Alias	Status
n/a	

Date	Comments
n/a	n/a

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
2A	0	0.08	n/a	20-MAY-2008

Source	Type	Method	Date issued	Issued By
229793	ADJUSTMENT	NEWGAN	1-JUL-2004	GLENN JONES

Previous Reference	Location	File Number
200035	n/a	T 14377.2

Comments
RE-UPDATE USING QLD 1R1 SPINE SECTION

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
LA	L1	n/a	n/a	6-JAN-2004

Source	Type	Method	Date issued	Issued By
229331	LEVELLING	LEVADJ	6-JAN-2004	GLENN JONES

Previous Reference	Location	File Number
4158 (SS 6279) 4159 (TS 6600)	MEERSCHAUM	n/a

Comments
SUPERCEDES ORIGINAL SECTION DUE TO RE-CALCULATION OF 202-203 (SSM 6279)

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
6600-2	DRILL HOLE IN CONC	241° 02' 58.3"	5.601	-1.563

Alias	Status
n/a	

Date	Comments
n/a	n/a

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
2A	0	0.08	n/a	20-MAY-2008

Source	Type	Method	Date issued	Issued By
229793	ADJUSTMENT	NEWGAN	1-JUL-2004	GLENN JONES

Previous Reference	Location	File Number
200035	n/a	T 14377.2

Comments
RE-UPDATE USING QLD 1R1 SPINE SECTION

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
LA	L1	n/a	n/a	6-JAN-2004

Source	Type	Method	Date issued	Issued By
229331	LEVELLING	LEVADJ	6-JAN-2004	GLENN JONES

Previous Reference	Location	File Number
4158 (SS 6279) 4159 (TS 6600)	MEERSCHAUM	n/a

Comments
SUPERCEDES ORIGINAL SECTION DUE TO RE-CALCULATION OF 202-203 (SSM 6279)

WITNESS MARK

To	Monument	GDA Azimuth	Spheroidal Distance	Height Difference
6600-1	GI PIPE IN CONC	210° 56' 16.8"	3.615	-1.566

Alias	Status
n/a	

Date	Comments
n/a	n/a

GDA94

Class	Order	Positional Uncertainty	Local Uncertainty	GDA Updated
2A	0	0.08	n/a	20-MAY-2008

Source	Type	Method	Date issued	Issued By
229793	ADJUSTMENT	NEWGAN	1-JUL-2004	GLENN JONES

Previous Reference	Location	File Number
200035	n/a	T 14377.2

Comments
RE-UPDATE USING QLD 1R1 SPINE SECTION

AHD71

Class	Order	Positional Uncertainty	Local Uncertainty	AHD Updated
LA	L1	n/a	n/a	6-JAN-2004

Source	Type	Method	Date issued	Issued By
229331	LEVELLING	LEVADJ	6-JAN-2004	GLENN JONES

Previous Reference	Location	File Number
4158 (SS 6279) 4159 (TS 6600)	MEERSCHAUM	n/a

Comments
SUPERCEDES ORIGINAL SECTION DUE TO RE-CALCULATION OF 202-203 (SSM 6279)

TRIG STATION

Trig Type	55/11	Station Originally Established By
PILLAR	1659	ROYAL AUSTRALIAN SURVEY CORPS

GNB Approved	Reference	Reserve No.	Reserve Name
3-JAN-1975	36978	n/a	n/a

BEACON

Description	Date Placed	Placed By
MAST AND VANES	11-NOV-1980	LAND & PROPERTY INFORMATION - BATHURST

Vane Top Height	Vane Diameter
1.437	0.755

VISITATION LOG

Date	Organisation	Comments
31-MAY-2012	GRAEME DAVIES	STATION OCCUPIED, GPS SESSION.
16-MAY-2012	GRAEME DAVIES	STATION OCCUPIED FOR RTA SURVEY, BALLINA-WOODBURN PROJECT.
3-NOV-2010	DEPARTMENT OF LANDS - LISMORE	TS USED TO CO-ORDINATE AND LEVEL LIDAR POINT, NEARBY.
17-FEB-2009	DEPARTMENT OF LANDS - LISMORE	STATION OCCUPIED FOR CO-ORDINATION OF BALLINA CORS MONUMENT. MAST & VANES PAINTED.
23-NOV-2007	DEPARTMENT OF LANDS - LISMORE	STATION OCCUPIED FOR GPS SURVEY, RICHMOND VALLEY
9-AUG-2004	DEPARTMENT OF LANDS - LISMORE	STATION OCCUPIED
30-MAR-2004	DEPARTMENT OF LANDS - LISMORE	STATION OCCUPIED FOR 24HR GPS SESSION
22-JAN-2002	LAND & PROPERTY INFORMATION - BATHURST	TRIG FOUND IN GOOD CONDITION & OCCUPIED FOR SURVEY
12-JAN-2002	LAND & PROPERTY INFORMATION - BATHURST	PILLAR, MAST AND VANES FOUND INTACT
1-AUG-2001	LAND & PROPERTY INFORMATION - BATHURST	TRIG IN GOOD CONDITION AND OCCUPIED FOR SURVEY CONTROL
29-JUN-2001	LAND & PROPERTY INFORMATION - BATHURST	TRIG IN GOOD CONDITION AND OCCUPIED FOR SURVEY CONTROL
31-MAY-2001	LAND & PROPERTY INFORMATION - BATHURST	TRIG IN GOOD CONDITION AND OCCUPIED FOR SURVEY CONTROL
28-FEB-2001	DEPARTMENT OF LANDS - LISMORE	RECCE FOR BALLINA SHIRE GPS SURVEY
11-NOV-1980	LAND & PROPERTY INFORMATION - BATHURST	A GI PIPE, DRILL HOLE AND COPPER CARTRIDGE CASE HAVE BEEN FOUND SET IN CONCRETE ECCENTRIC TO PILLAR. A NAME PLATE HAS BEEN PLACED.

Appendix G Examples of Service Provider Solutions

AUSPOS GPS Processing Report

August 19, 2014

This document is a report of the GPS data processing undertaken by the AUSPOS Online GPS Processing Service (version: AUSPOS 2.1) . The AUSPOS Online GPS Processing Service uses International GNSS Service (IGS) products (final, rapid, ultra-rapid depending on availability) to compute precise coordinates in ITRF anywhere on Earth and GDA94 within Australia. The Service is designed to process only dual frequency GPS phase data.

An overview of the GPS processing strategy is included in this report.

Please direct any correspondence to geodesy@ga.gov.au

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Cnr Jerrabomberra and Hindmarsh Drive
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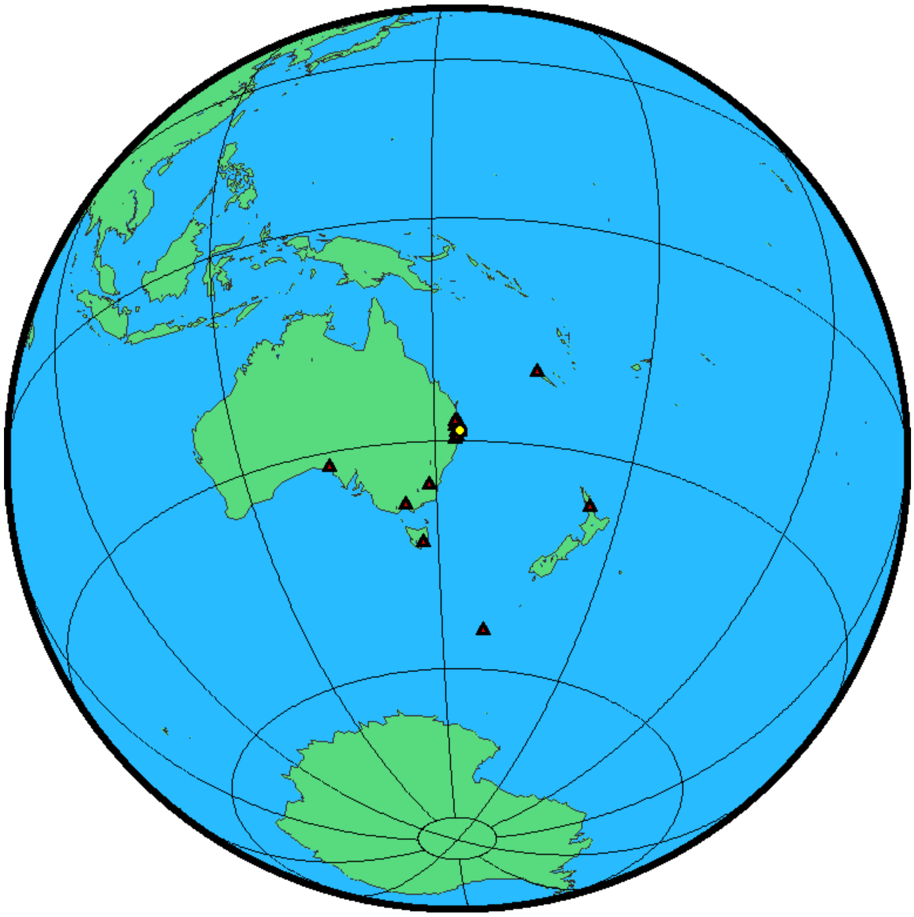
Geoscience Australia
Home Page: http://www.ga.gov.au

1 User Data

All antenna heights refer to the vertical distance from the Ground Mark to the Antenna Reference Point (ARP).

Station (s)	Submitted File	Antenna Type	Antenna Height (m)	Start Time	End Time
HAYA	HayA2280.14o	LEIGS14 NONE	0.190	2014/08/16 02:01:00	2014/08/17 04:19:30

2 Processing Summary



Date	User Stations	Reference Stations	Orbit Type
2014/08/16 02:01:00	HAYA	AUCK BALN BDST CEDU CLEV CSNO GFTN HOB2 KOUC MAC1 MOBS ROBI TID1 WOOL YMBA	IGS rapid

Remark: An IGS Rapid Orbit product has been used in this computation, IGS Rapid orbits are usually of very high quality. However, to ensure you achieve the highest quality coordinates please resubmit approximately 2 weeks after the observation session end to ensure the use of the IGS Final Orbit product.

3 Computed Coordinates, GDA94

For Australian users Geocentric Datum of Australia (GDA94, ITRF92@1994.0) coordinates are provided. GDA94 coordinates are determined from ITRF coordinates by Geoscience Australia (GA) derived coordinate transformation process. GA recommends that users within Australia use GDA94 coordinates. For general and technical information on GDA94 see http://www.ga.gov.au/earth-monitoring/geodesy/geodetic-datums/GDA.html and http://www.icsm.gov.au/icsm/gda/gdatm/

3.1 Cartesian, GDA94

Station	X (m)	Y (m)	Z (m)
HAYA	-5016178.546	2490101.595	-3042624.766
BALN	-5005205.882	2488517.130	-3061572.449
BDST	-5021920.618	2559339.871	-2975290.669
CEDU	-3753472.146	3912741.043	-3347961.041
CLEV	-5055208.999	2546205.936	-2930072.261
CSNO	-4982926.729	2533719.026	-3060895.274
GFTN	-4937895.560	2523271.994	-3140889.525
HOB2	-3950071.276	2522415.209	-4311638.527
MOBS	-4130635.792	2894953.097	-3890531.463
ROBI	-5034843.824	2523322.872	-2984064.620
TID1	-4460996.060	2682557.130	-3674443.859
WOOL	-5046788.340	2567555.319	-2926034.798
YMBA	-4968471.737	2492594.013	-3117204.658

3.2 Geodetic, GRS80 Ellipsoid, GDA94

AHD is computed from an Australia wide gravimetric geoid model that has been aposteriori fitted to AHD. The derived AHD is only provided for sites within the extents of the AUSGEOID09 (Version 1.01) product, see http://www.ga.gov.au/earth-monitoring/geodesy/geodetic-datums/geoid.html.

Station	Latitude (DMS)	Longitude (DMS)	Ellipsoidal Height(m)	Derived AHD (m)
HAYA	-28 40 37.51646	153 35 58.38546	154.968	116.728
BALN	-28 52 21.62988	153 33 50.71995	44.5333	6.992
BDST	-27 59 13.56947	152 59 42.27829	101.1030	60.709
CEDU	-31 52 00.01667	133 48 35.37576	144.8211	153.615
CLEV	-27 31 34.17661	153 15 59.52285	67.0021	25.398
CSNO	-28 51 56.07348	153 02 51.25240	69.0930	31.304
GFTN	-29 41 34.93213	152 55 58.43943	59.2109	23.778
HOB2	-42 48 16.98550	147 26 19.43584	41.1344	44.752
MOBS	-37 49 45.89888	144 58 31.20680	40.6790	35.904
ROBI	-28 04 37.08904	153 22 52.50854	65.2929	25.089
TID1	-35 23 57.15615	148 58 47.98452	665.4186	646.347
WOOL	-27 29 05.88831	153 02 06.96445	91.0524	49.246
YMBA	-29 26 50.80002	153 21 28.41364	43.6343	7.784

3.3 MGA Grid, GRS80 Ellipsoid, GDA94

Station	East (m)	North (m)	Zone	Ellipsoidal Height (m)	Derived AHD (m)
HAYA	558577.426	6827642.343	56	154.968	116.728
BALN	555009.892	6805990.014	56	44.533	6.991
BDST	499515.930	6904226.326	56	101.103	60.709
CEDU	387415.777	6473725.239	53	144.821	153.615
CLEV	526320.100	6955257.199	56	67.002	25.398
CSNO	504639.308	6806906.336	56	69.093	31.304
GFTN	493508.520	6715225.993	56	59.211	23.778
HOB2	535873.404	5260777.216	55	41.134	44.752
MOBS	321819.595	5811180.037	55	40.679	35.904
ROBI	537459.181	6894212.654	56	65.293	25.089
TID1	679807.860	6080884.473	55	665.419	646.347
WOOL	503483.976	6959847.631	56	91.052	49.246
YMBA	534707.656	6742386.425	56	43.634	7.783

3.4 Positional Uncertainty (95% C.L.) - Geodetic, GDA94

Station	Longitude(East) (m)	Latitude(North) (m)	Ellipsoidal Height(Up) (m)
HAYA	0.008	0.008	0.018
AUCK	0.008	0.008	0.018
BALN	0.008	0.008	0.018
BDST	0.008	0.008	0.018
CEDU	0.008	0.008	0.019
CLEV	0.008	0.008	0.018
CSNO	0.008	0.008	0.018
GFTN	0.008	0.008	0.018
HOB2	0.008	0.008	0.017
KOUC	0.008	0.008	0.018
MAC1	0.008	0.009	0.017
MOBS	0.008	0.008	0.017
ROBI	0.008	0.008	0.018
TID1	0.008	0.008	0.018
WOOL	0.008	0.008	0.018
YMBA	0.008	0.008	0.018

3.5 ITRF to GDA94 Transformation Parameters

Transformation parameters between ITRF 2008 and GDA 94 are calculated on a solution by solution basis via a Helmert Transformation using the parameters and approach detailed in ITRF to GDA94 Coordinate Transformations, J.Dawson and A.Woods, Journal of Applied Geodesy, 4(2010), no.4, pp. 189-199.

$$\begin{pmatrix} X_{GDA94} \\ Y_{GDA94} \\ Z_{GDA94} \end{pmatrix} = \begin{pmatrix} T_x \\ T_y \\ T_z \end{pmatrix} + (1 + S_c) \begin{pmatrix} 1 & R_z & -R_y \\ -R_z & 1 & R_x \\ R_y & -R_x & 1 \end{pmatrix} \begin{pmatrix} X_{ITRF} \\ Y_{ITRF} \\ Z_{ITRF} \end{pmatrix}$$

where

$$\begin{aligned} T_x &= -0.05540(m) \\ T_y &= 0.00821(m) \\ T_z &= 0.05057(m) \\ S_c &= 1.1958e-08 \\ R_x &= 1.52520e-07(radians) \\ R_y &= 1.29125e-07(radians) \\ R_z &= 1.27133e-07(radians) \end{aligned}$$

The above transformation parameters are only valid for the epoch 16/08/2014.

4 Computed Coordinates, ITRF2008

All computed coordinates are based on the IGS realisation of the ITRF2008 reference frame. All the given ITRF2008 coordinates refer to a mean epoch of the site observation data. All coordinates refer to the Ground Mark.

4.1 Cartesian, ITRF2008

Station	X (m)	Y (m)	Z (m)	ITRF2008 @
HAYA	-5016179.140	2490101.383	-3042623.753	16/08/2014
AUCK	-5105681.406	461564.006	-3782181.174	16/08/2014
BALN	-5005206.479	2488516.922	-3061571.438	16/08/2014
BDST	-5021921.213	2559339.647	-2975289.645	16/08/2014
CEDU	-3753472.975	3912741.021	-3347959.971	16/08/2014
CLEV	-5055209.585	2546205.702	-2930071.236	16/08/2014
CSNO	-4982927.332	2533718.820	-3060894.258	16/08/2014
GFTN	-4937896.172	2523271.807	-3140888.516	16/08/2014
HOB2	-3950072.050	2522415.326	-4311637.631	16/08/2014
KOUC	-5751223.012	1617967.328	-2225743.418	16/08/2014
MAC1	-3464038.796	1334173.109	-5169223.992	16/08/2014
MOBS	-4130636.558	2894953.123	-3890530.493	16/08/2014
ROBI	-5034844.414	2523322.648	-2984063.600	16/08/2014
TID1	-4460996.767	2682557.084	-3674442.880	16/08/2014
WOOL	-5046788.928	2567555.085	-2926033.770	16/08/2014
YMBA	-4968472.342	2492593.819	-3117203.650	16/08/2014

4.2 Geodetic, GRS80 Ellipsoid, ITRF2008

Geoid-ellipsoidal separations, in this section, are computed using a spherical harmonic synthesis of the global EGM2008 geoid. More information on the EGM2008 geoid can be found at http://earth-info.nga.mil/GandG/wgs84/gravitymod/egm2008/

Station	Latitude (DMS)	Longitude (DMS)	Ellipsoidal Height(m)	Derived Above Geoid Height(m)
HAYA	-28 40 37.48076	153 35 58.40218	154.866	117.088
AUCK	-36 36 10.22124	174 50 03.79051	132.684	97.751
BALN	-28 52 21.59417	153 33 50.73660	44.432	7.349
BDST	-27 59 13.53358	152 59 42.29545	101.000	61.007
CEDU	-31 51 59.97757	133 48 35.39910	144.730	153.773
CLEV	-27 31 34.14079	153 15 59.54009	66.899	25.748
CSNO	-28 51 56.03762	153 02 51.26922	68.991	31.648
GFTN	-29 41 34.89625	152 55 58.45599	59.110	24.107
HOB2	-42 48 16.94844	147 26 19.44985	41.051	44.764
KOUC	-20 33 31.28045	164 17 14.41820	84.128	23.681
MAC1	-54 29 58.30093	158 56 08.98987	-6.804	12.208
MOBS	-37 49 45.86125	144 58 31.22392	40.590	35.998
ROBI	-28 04 37.05326	153 22 52.52554	65.190	25.421
TID1	-35 23 57.11934	148 58 48.00055	665.326	646.479
WOOL	-27 29 05.85242	153 02 06.98178	90.949	49.632
YMBA	-29 26 50.76426	153 21 28.43014	43.533	8.163

4.3 Positional Uncertainty (95% C.L.) - Geodetic, ITRF2008

Station	Longitude(East) (m)	Latitude(North) (m)	Ellipsoidal Height(Up) (m)
HAYA	0.004	0.005	0.011
AUCK	0.006	0.005	0.012
BALN	0.004	0.005	0.011
BDST	0.004	0.005	0.011
CEDU	0.005	0.005	0.012
CLEV	0.004	0.005	0.011
CSNO	0.004	0.005	0.011
GFTN	0.004	0.005	0.011
HOB2	0.004	0.005	0.010
KOUC	0.006	0.005	0.011
MAC1	0.006	0.005	0.010
MOBS	0.004	0.004	0.009
ROBI	0.004	0.005	0.011
TID1	0.004	0.005	0.010
WOOL	0.005	0.005	0.011
YMBA	0.004	0.005	0.011

5 Ambiguity Resolution - Per Baseline

Baseline	Ambiguities Resolved	Baseline Length (km)
MOBS - ROBI	79.4 %	1333.2
BDST - CLEV	80.0 %	57.7
AUCK - MAC1	88.9 %	2319.6
MAC1 - MOBS	91.5 %	2125.0
HOB2 - MOBS	90.3 %	590.5
CLEV - ROBI	78.1 %	62.1
MOBS - TID1	93.5 %	448.3
BALN - YMBA	78.8 %	66.8
CEDU - TID1	93.2 %	1456.2
CLEV - KOUC	71.4 %	1357.3
CSNO - ROBI	81.2 %	93.3
HAYA - YMBA	82.3 %	88.6
ROBI - YMBA	78.6 %	151.9
GFTN - ROBI	68.9 %	184.4
CLEV - WOOL	70.4 %	23.3
AVERAGE	81.0%	690.5

Please note for a regional solution, such as used by AUSPOS, an average ambiguity resolution of 50% or better for the network indicates a reliable solution.

6 Computation Standards

6.1 Computation System

Software	Bernese GPS Software Version 5.0.
GNSS system(s)	GPS only.

6.2 Data Preprocessing and Measurement Modelling

Data preprocessing	Phase preprocessing is undertaken in a baseline by baseline mode using triple-differences. In most cases, cycle slips are fixed by the simultaneous analysis of different linear combinations of L1 and L2. If a cycle slip cannot be fixed reliably, bad data points are removed or new ambiguities are set up A data screening step on the basis of weighted postfit residuals is also performed, and outliers are removed.
Basic observable	Carrier phase with an elevation angle cutoff of 10° and a sampling rate of 3 minutes. However, data cleaning is performed a sampling rate of 30 seconds. Elevation dependent weighting is applied according to $1/\sin(e)^2$ where e is the satellite elevation. The code observable is only used for the receiver clock synchronisation.
Modelled observable	Double differences of the ionosphere-free linear combination.
Ground antenna phase centre calibrations	IGS08 absolute phase-centre variation model is applied.
Tropospheric Model	A priori model is the Saastamoinen-based hydrostatic mapped with the dry-Niell.
Tropospheric Estimation	Zenith delay corrections are estimated relying on the wet-Niell mapping function in intervals of 2 hour. N-S and E-W horizontal delay parameters are solved for every 24 hours.
Tropospheric Mapping Function	Niell
Ionosphere	First-order effect eliminated by forming the ionosphere-free linear combination of L1 and L2.
Tidal displacements	Solid earth tidal displacements are derived from the complete model from the IERS Conventions 2003, but ocean tide loading is not applied.
Atmospheric loading	Not applied
Satellite centre of mass correction	IGS08 phase-centre variation model applied
Satellite phase centre calibration	IGS08 phase-centre variation model applied
Satellite trajectories	Best available IGS products.
Earth Orientation	Best available IGS products.

6.3 Estimation Process

Adjustment	Weighted least-squares algorithm.
Station coordinates	Coordinate constraints are applied at the Reference sites with standard deviation of 1mm and 2mm for horizontal and vertical components respectively.
Troposphere	Zenith delay parameters and pairs of horizontal delay gradient parameters are estimated for each station in intervals of 2 hour and 24 hours.
Ionospheric correction	An ionospheric map derived from the contributing reference stations is used to aid ambiguity resolution using the QIF strategy
Ambiguity	Ambiguities are resolved in a baseline-by-baseline mode using Quasi-Ionosphere-Free (QIF) approach.

6.4 Reference Frame and Coordinate Uncertainty

Terrestrial reference frame	IGS08 station coordinates and velocities mapped to the mean epoch of observation.
Australian datum	GDA94 coordinates determined via Helmert transformation from ITRF using the Dawson and Woods (2010) parameters.
Derived AHD	For stations within Australia, AUSGeoid09 is used to compute AHD. AUSGeoid09 is the Australia-wide gravimetric quasigeoid model that has been a posteriori fitted to the Australian Height Datum
Above-geoid heights	Earth Gravitational Model EGM2008 released by the National Geospatial-Intelligence Agency (NGA) EGM Development Team is used to compute above-geoid heights. This gravitational model is complete to spherical harmonic degree and order 2159, and contains additional coefficients extending to degree 2190 and order 2159.
Coordinate uncertainty	Coordinate uncertainty is expressed in terms of the 95% confidence level for both GDA94 and ITRF2008. Uncertainties are scaled using an empirically derived model which is a function of data span, quality and geographical location.

Danny O'Sullivan <leftyos@gmail.com>

OPUS solution : HayA2280.14o OP1408427047203

opus <opus@ngs.noaa.gov> Tue, Aug 19, 2014 at 3:48 PM
Reply-To: ngs.opus@noaa.gov
To: leftyos@gmail.com

FILE: HayA2280.14o OP1408427047203

NGS OPUS SOLUTION REPORT
========================

All computed coordinate accuracies are listed as peak-to-peak values.
For additional information: http://www.ngs.noaa.gov/OPUS/about.jsp#accuracy

```
      USER: leftyos@gmail.com                DATE: August 19, 2014
RINEX FILE: haya228c.14o                     TIME: 05:48:06 UTC

  SOFTWARE: page5  1209.04 master93.pl 022814      START: 2014/08/16  02:01:00
 EPHEMERIS: igr18056.eph [rapid]                    STOP: 2014/08/17  04:19:00
  NAV FILE: brdc2280.14n                       OBS USED: 63640 / 65785   :  97%
  ANT NAME: LEIGS14         NONE            # FIXED AMB:   196 /   214   :  92%
ARP HEIGHT: 0.19                          OVERALL RMS: 0.015(m)

 REF FRAME: IGS08 (EPOCH:2014.6236)

         X:     -5016179.138(m)   0.002(m)
         Y:      2490101.383(m)   0.005(m)
         Z:     -3042623.760(m)   0.006(m)

       LAT:  -28 40 37.48099      0.004(m)
     E LON:  153 35 58.40214      0.005(m)
     W LON:  206 24  1.59786      0.005(m)
    EL HGT:         154.868(m)   0.005(m)

                    UTM COORDINATES
                     UTM (Zone 56)
Northing (Y) [meters]     6827643.433
Easting (X)  [meters]      558577.884
Convergence  [degrees]    -0.28771874
Point Scale               0.99964235
Combined Factor           0.99961803

                       BASE STATIONS USED
PID       DESIGNATION                      LATITUDE    LONGITUDE DISTANCE(m)
       SYDN                                                   611812.1
       STR1                                                   853517.3
       TIDB                                                   862822.2
```

This position and the above vector components were computed without any knowledge by the National Geodetic Survey regarding the equipment or field operating procedures used.

CSRS-PPP (V 1.05 34613)

0567081714194394

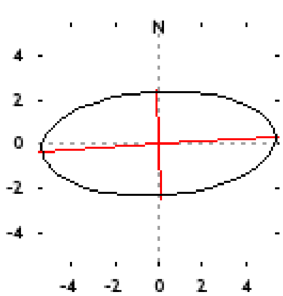
Data Start	Data End	Duration of Observations
2014-08-16 02:01:00.000	2014-08-17 04:19:45.000	26h 18m 45.00s
Apri / Aposteriori Phase Std		**Apri / Aposteriori Code Std**
0.015m / 0.010m		2.0m / 0.353m
Observations	**Frequency**	**Mode**
Phase and Code	L1 and L2	Static
Elevation Cut-Off	**Rejected Epochs**	**Observation & Estimation Steps**
10.000 degrees	0.00 %	15.00 sec / 15.00 sec
Antenna Model	**APC to ARP**	**ARP to Marker**
LEIGS14	L1= 0.089 m L2= 0.089 m	0.190 m

(APC = antenna phase center; ARP = antenna reference point)

Estimated Position for HayA2280.14o

	Latitude (+n)	Longitude (+e)	Ell. Height
ITRF08 (2014)	-28º 40’ 37.4809’’	153º 35’ 58.4020’’	154.861 m
Sigmas(95%)	0.002 m	0.004 m	0.010 m
Apriori	-28º 40’ 37.506’’	153º 35’ 58.409’’	154.666 m
Estimated - Apriori	0.781 m	-0.191 m	0.195 m

95% Error Ellipse (mm)
semi-major: 5.377mm
semi-minor: 2.357mm
semi-major azimuth: 86º 44’ 55.00’’



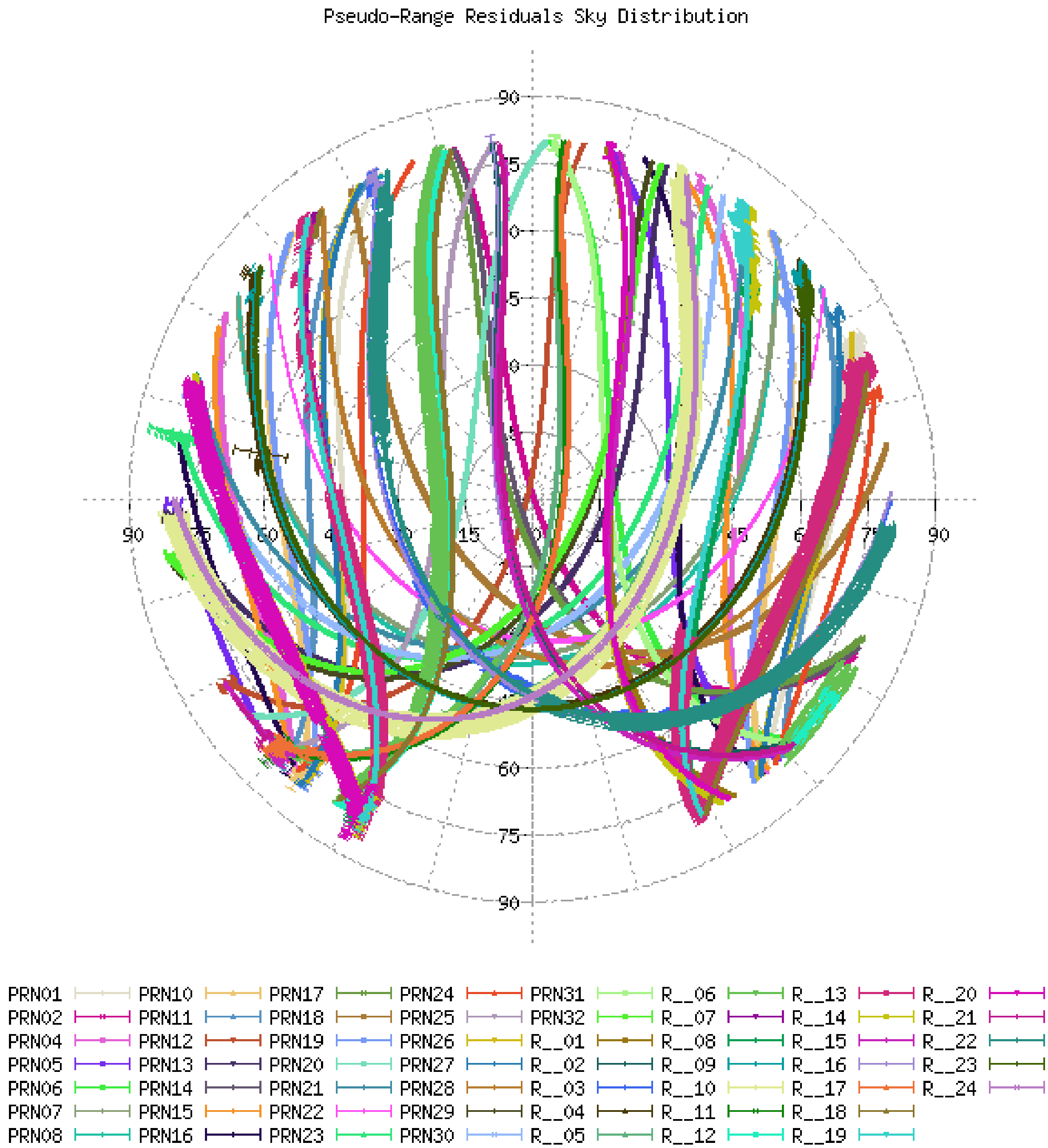
UTM (South) Zone 56

6827643.435m (N) 558577.880m (E)

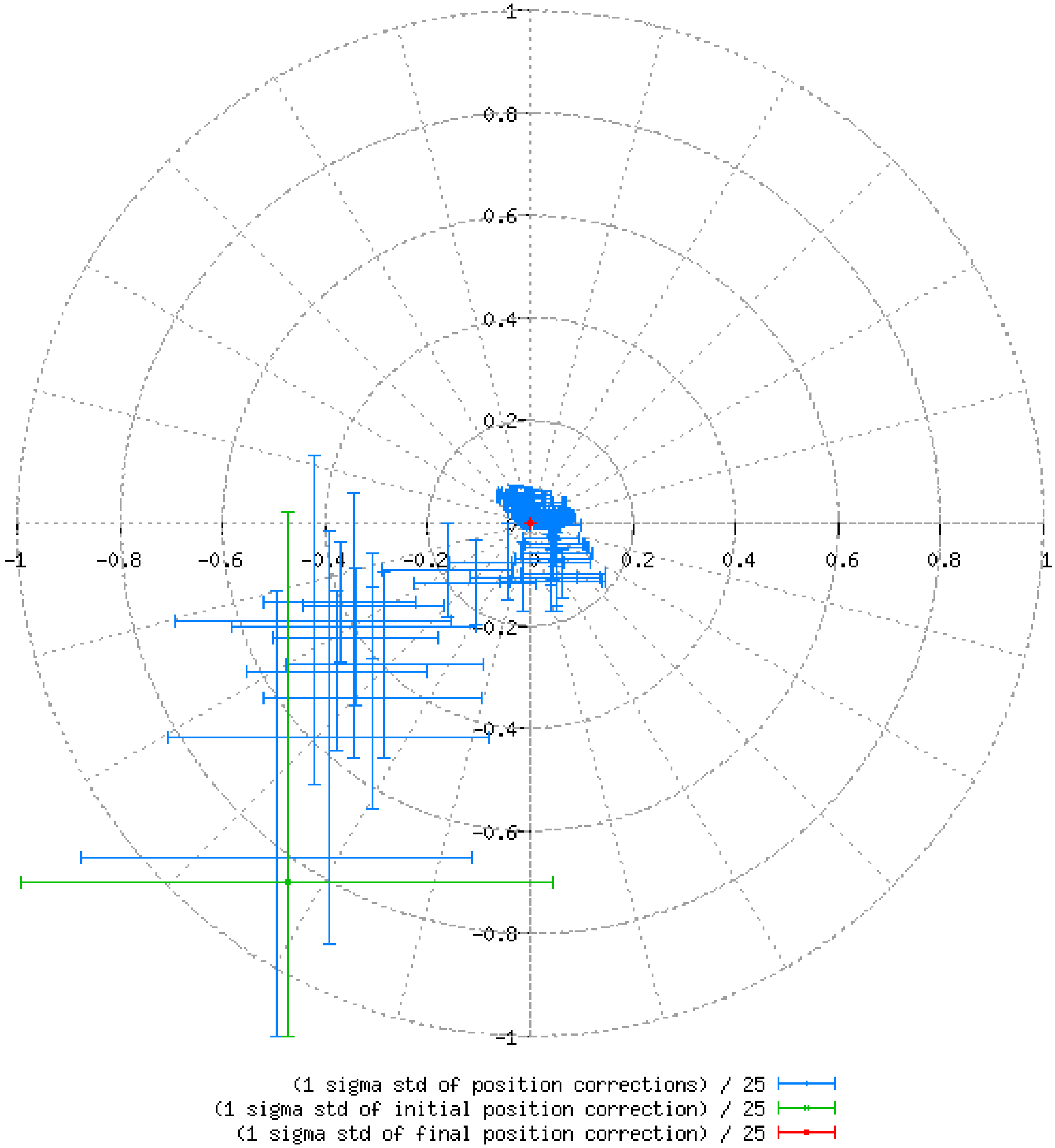
Scale Factors
0.99964235 (point)
0.99961805 (combined)

(Coordinates from RINEX file used as apriori position)

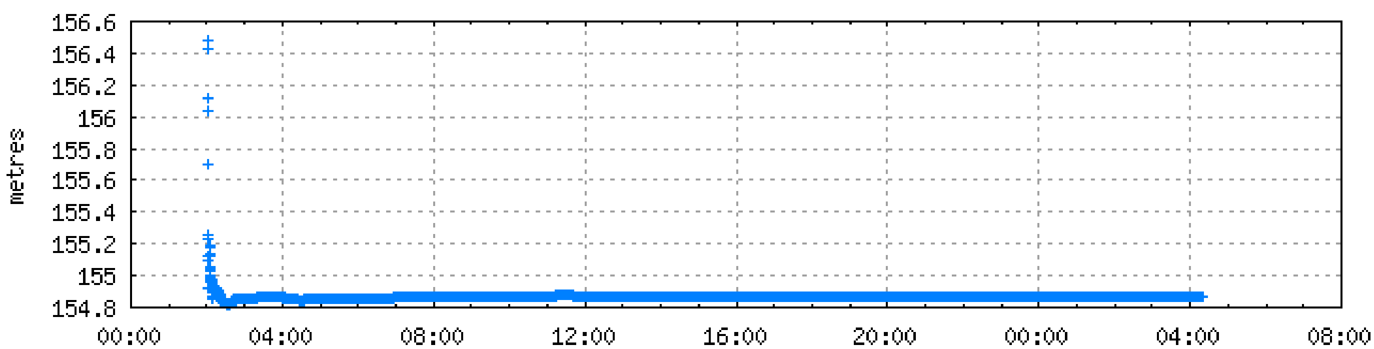
Estimated Parameters & Observations Statistics

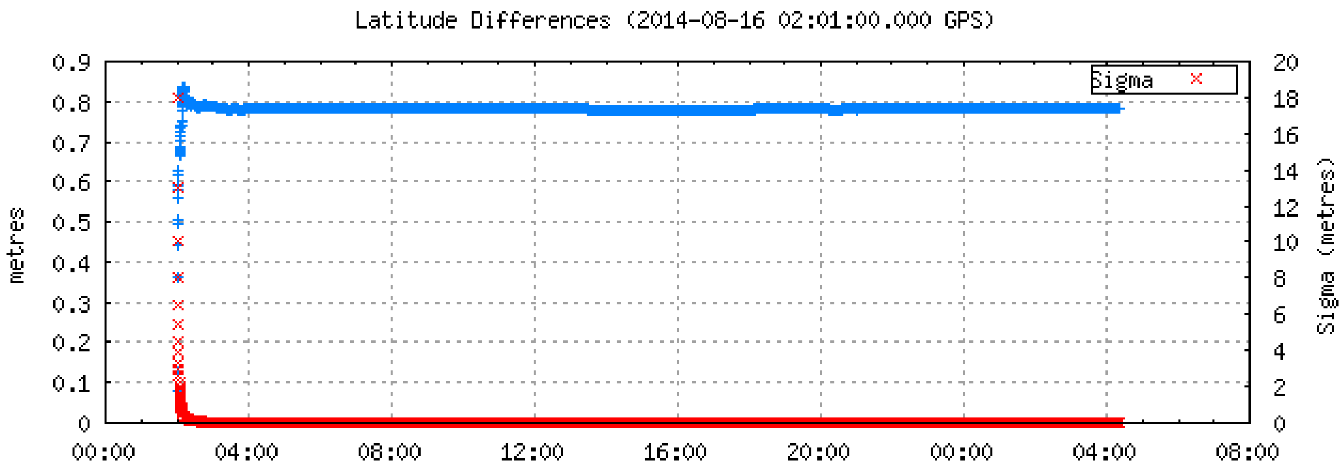


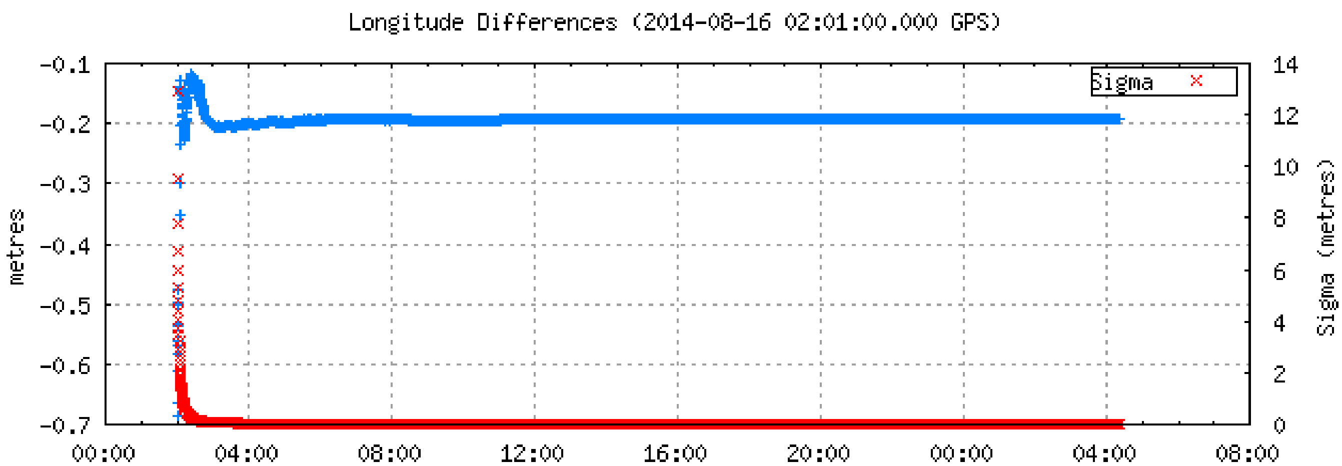
Corrections to apriori position (minus final corrections) (metres)

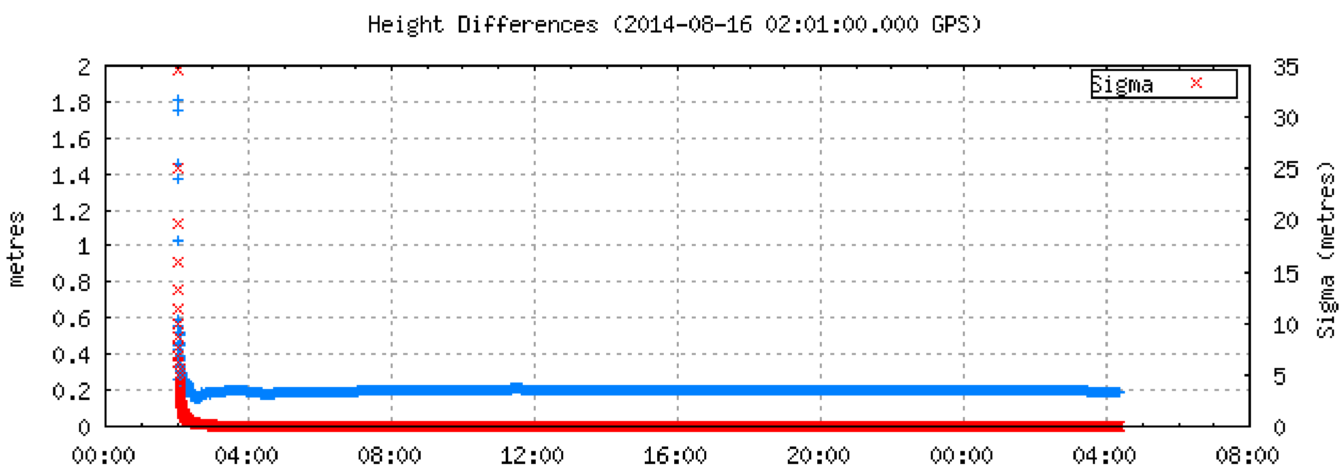


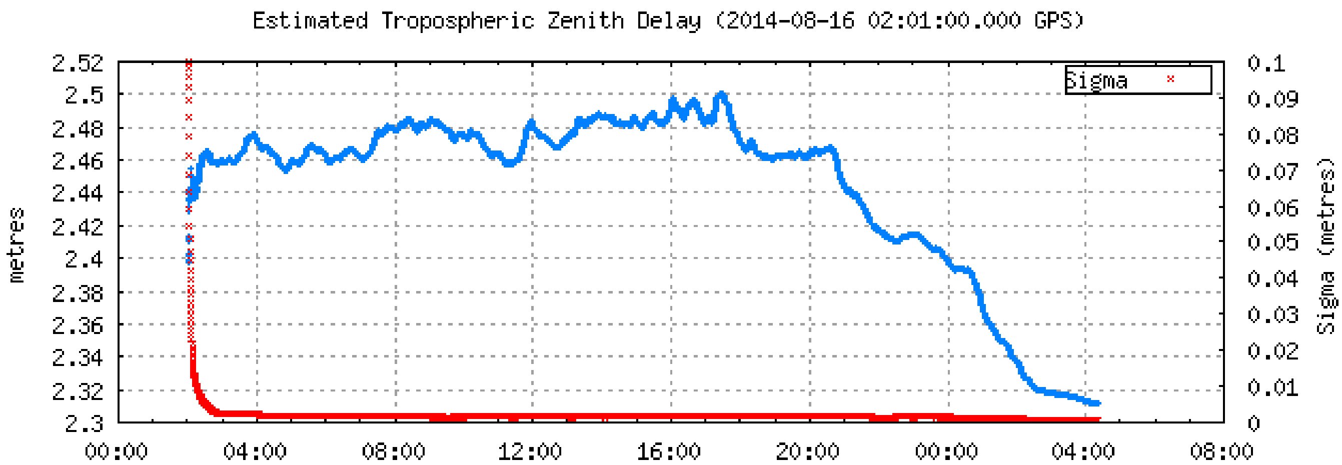
Ellipsoidal Height Profile (2014-08-16 02:01:00.000 GPS)



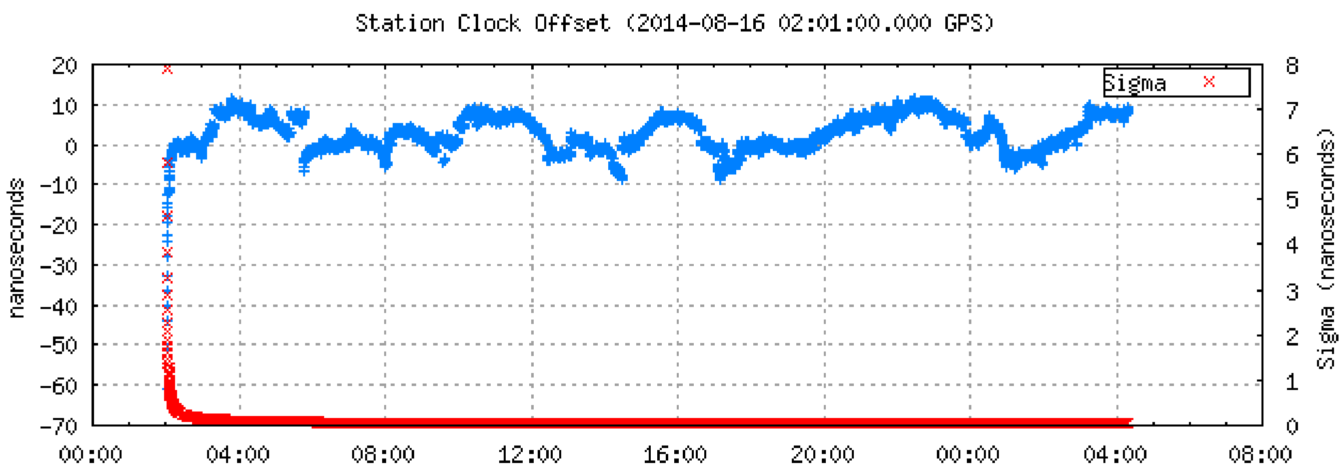

Latitude Differences (2014-08-16 02:01:00.000 GPS)
metres
Sigma (metres)
Sigma
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
20
18
16
14
12
10
8
6
4
2
0
00:00
04:00
08:00
12:00
16:00
20:00
00:00
04:00
08:00


Longitude Differences (2014-08-16 02:01:00.000 GPS)
metres
Sigma (metres)
Sigma
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
14
12
10
8
6
4
2
0
00:00
04:00
08:00
12:00
16:00
20:00
00:00
04:00
08:00

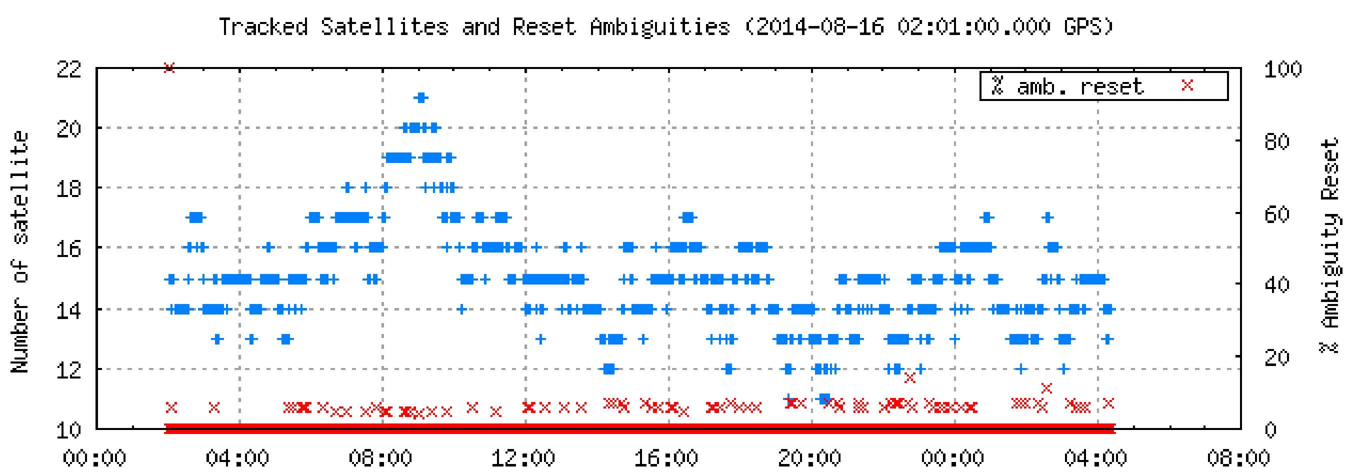

Height Differences (2014-08-16 02:01:00.000 GPS)
metres
Sigma (metres)
Sigma
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
35
30
25
20
15
10
5
0
00:00
04:00
08:00
12:00
16:00
20:00
00:00
04:00
08:00



Estimated Tropospheric Zenith Delay (2014-08-16 02:01:00.000 GPS)
Sigma
metres
Sigma (metres)
2.52
2.5
2.48
2.46
2.44
2.42
2.4
2.38
2.36
2.34
2.32
2.3
0.1
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
00:00
04:00
08:00
12:00
16:00
20:00
00:00
04:00
08:00

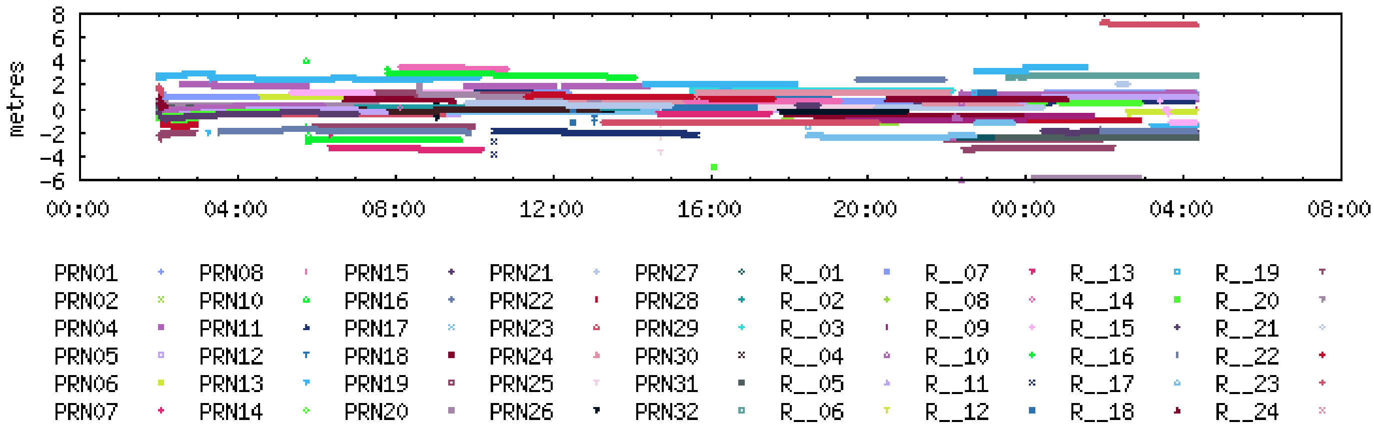


Station Clock Offset (2014-08-16 02:01:00.000 GPS)
Sigma
nanoseconds
Sigma (nanoseconds)
20
10
0
-10
-20
-30
-40
-50
-60
-70
8
7
6
5
4
3
2
1
0
00:00
04:00
08:00
12:00
16:00
20:00
00:00
04:00
08:00

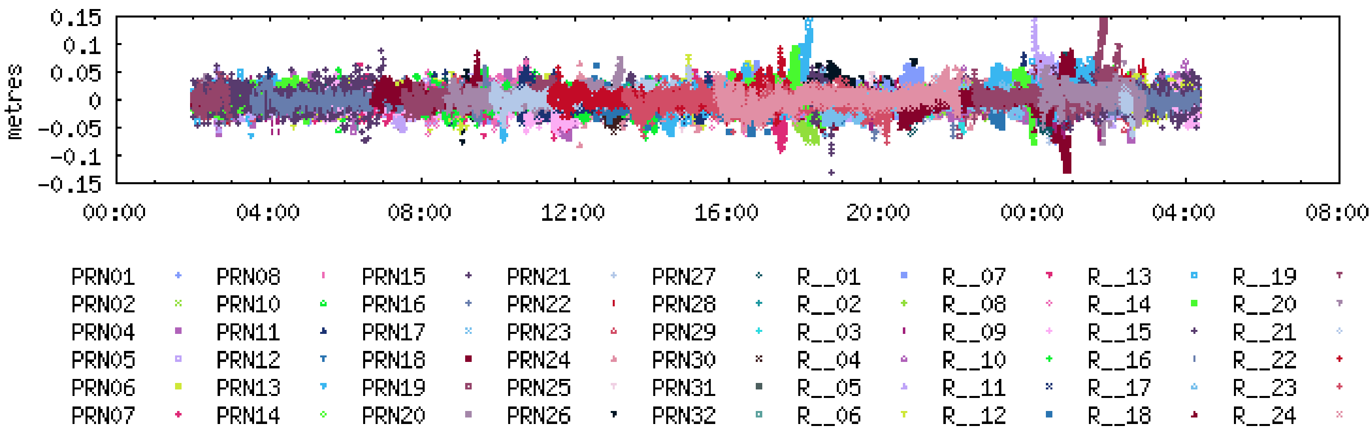


Tracked Satellites and Reset Ambiguities (2014-08-16 02:01:00.000 GPS)
% amb. reset
Number of satellite
% Ambiguity Reset
22
20
18
16
14
12
10
100
80
60
40
20
0
00:00
04:00
08:00
12:00
16:00
20:00
00:00
04:00
08:00

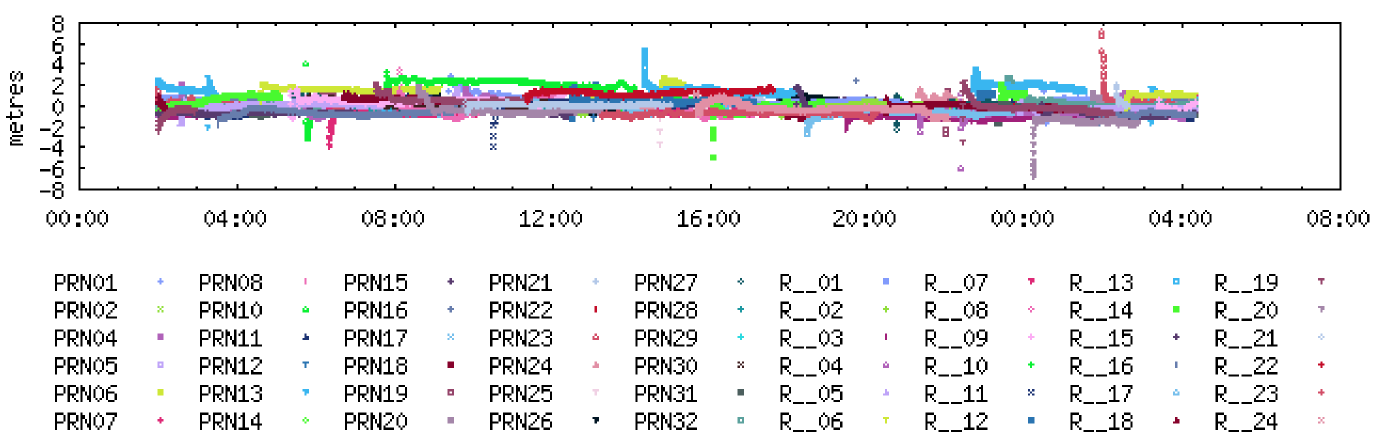
Ambiguities (2014-08-16 02:01:00.000 GPS)



Carrier-Phase Residuals (2014-08-16 02:01:00.000 GPS)



Pseudo-Range Residuals (2014-08-16 02:01:00.000 GPS)



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Phone:613-995-4410 FAX: 613-995-3215
EMail: information@geod.nrcan.gc.ca

Natural Resources Canada   Ressources naturelles Canada

Canada

A product by

PPP REPORT

User: leftyos
Scenario: Sep 04 at 12:49:50
Start Date: 2014/08/16-00:00:00 (14228)
End Date: 2014/08/17-24:00:00 (14229)
Run Date: 2014/09/04-02:51:32 UTC

All times are GPS Time unless otherwise stated

QUALITY DATA, ALGORITHMS AND PRODUCTS
FOR THE GNSS USER COMMUNITY

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Table of Contents

1. CONFIGURATION SUMMARY

1.1. LIST OF STATIONS AND RINEX FILES

Number of stations: 1

haya

haya2280.14o

1.2. LIST OF SATELLITES

Number of satellites: 54

G01, G02, G04, G05, G06, G07, G08, G10, G11, G12, G13, G14, G15, G16, G17, G18, G19, G20, G21, G22, G23, G24, G25, G26, G27, G28, G29, G30, G31, G32, R01, R02, R03, R04, R05, R06, R07, R08, R09, R10, R11, R12, R13, R14, R15, R16, R17, R18, R19, R20, R21, R22, R23, R24

1.3. SETTINGS

Data Sampling Rate	30 s
Minimum Elevation Angle	10 deg
Number of Iterations	6
Reference Products	GMV Rapid

Table 1. Settings

2. PROCESSING SUMMARY

2.1. PARAMETER ESTIMATION

Total Measurements	Clock Parameters	Non Clock Parameters	Ambiguities
91358	5761	206	130

Table 2. Parameter estimation

2.2. CONVERGENCE

A priori weight of code measurements: 0.250 m (GPS) / 0.300 m (GLONASS)

A priori weight of phase measurements: 0.006 m (GPS) / 0.006 m (GLONASS)

Iteration Number	RMS of Weighted Residuals	Delta RMS of Weighted Residuals	RMS of Code Residuals m	RMS of Phase Residuals m
0	447.799	-	3.803	3.799
1	3.628	444.171	0.335	0.030
2	1.879	1.749	0.328	0.014
3	1.729	0.150	0.328	0.013
4	1.688	0.041	0.327	0.012
5	1.670	0.018	0.327	0.012
6	1.668	0.002	0.327	0.012

Table 3. Convergence

2.3. REJECTED STATIONS AND SATELLITES

Rejected Stations: None

Rejected Satellites: None

2.4. NUMBER OF USED AND REJECTED MEASUREMENTS

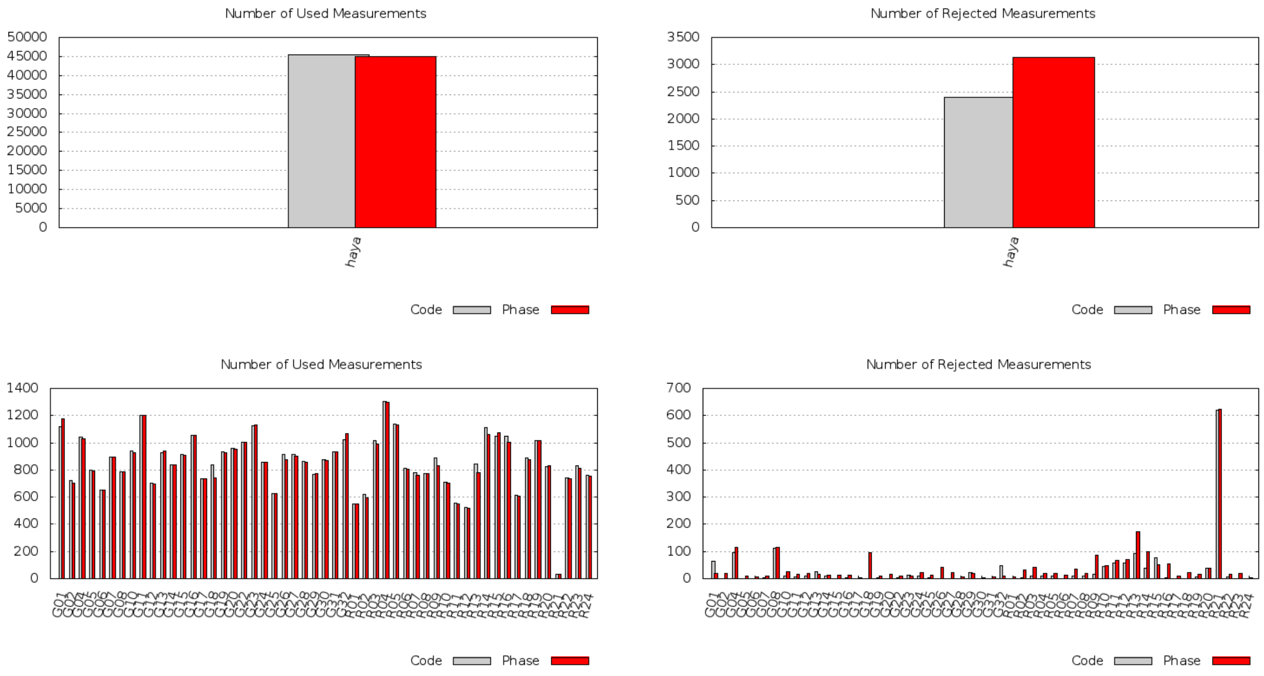


Table 4. Number of Used and Rejected Measurements

2.5. MEASUREMENT RESIDUALS

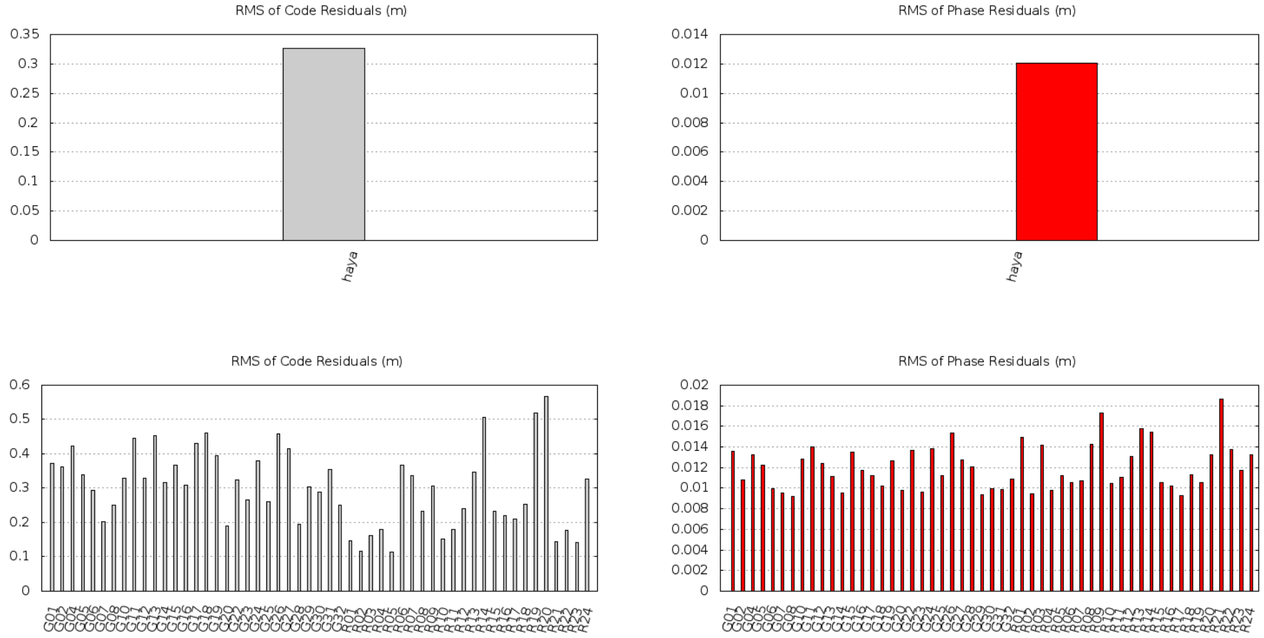


Table 5. RMS of Residuals

2.6. RESIDUALS VS ELEVATION

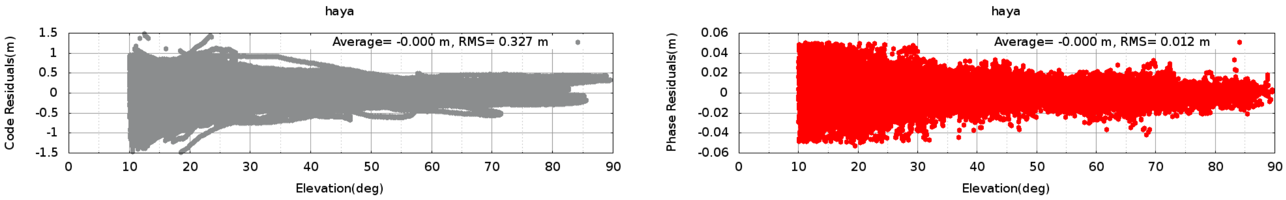
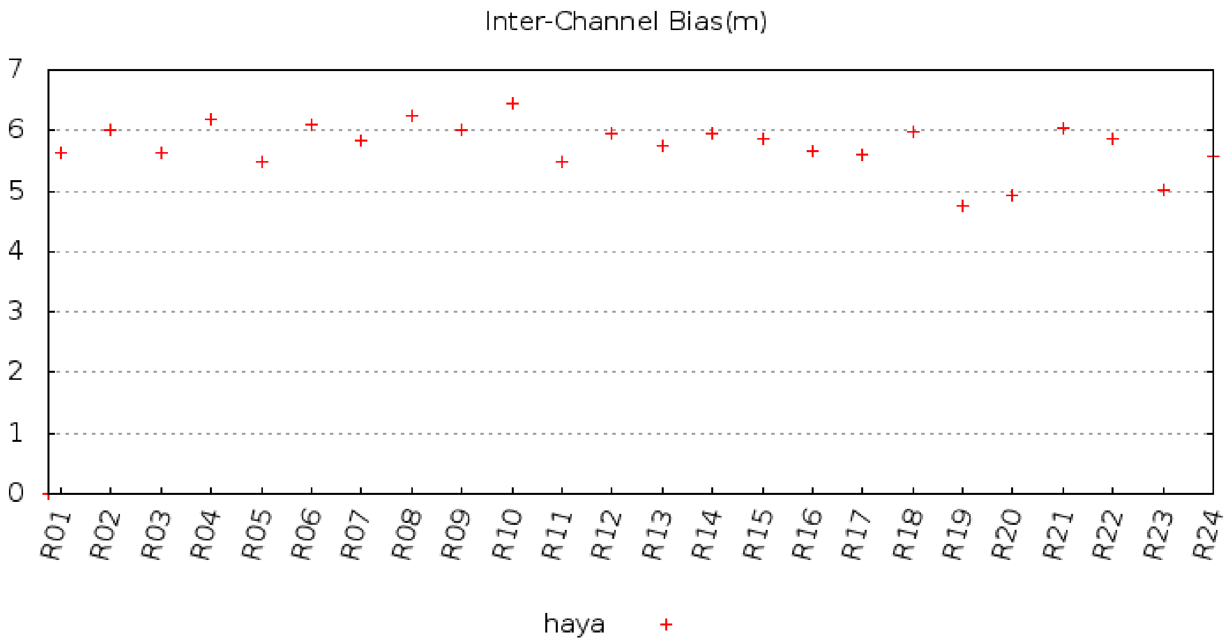


Table 6. Residuals vs. Elevation

3. PRODUCTS SUMMARY

3.1. INTER-CHANNEL BIASES



3.2. ZENITH TROPOSPHERIC DELAY

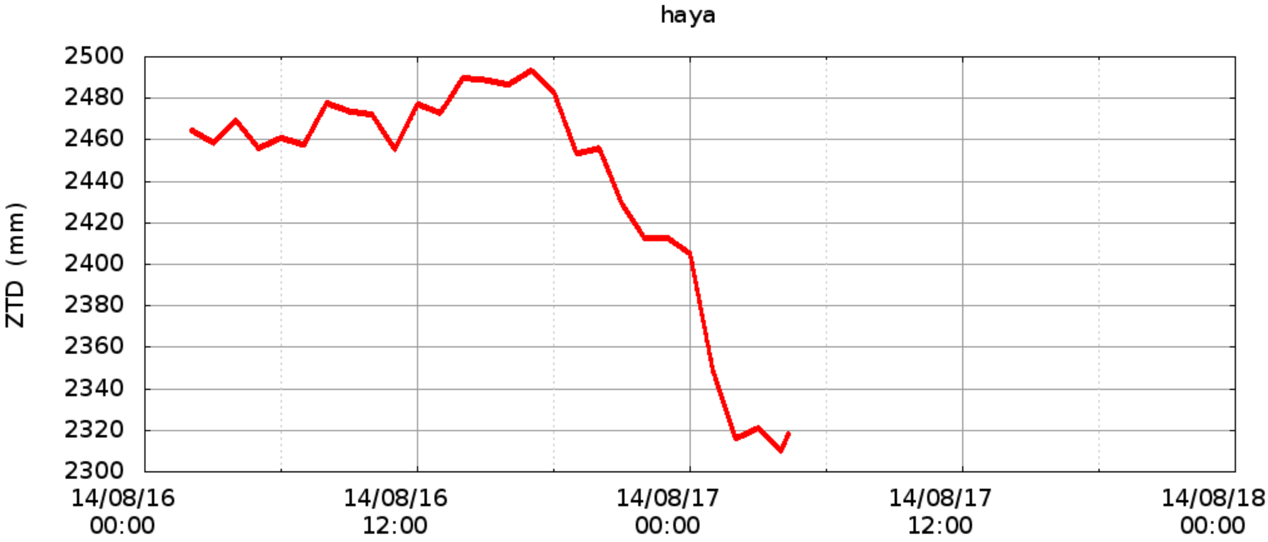


Table 7. Zenith Tropospheric Delay

3.3. STATION CLOCKS

The following figures show the clock offset with respect to GMV Internal time scale:

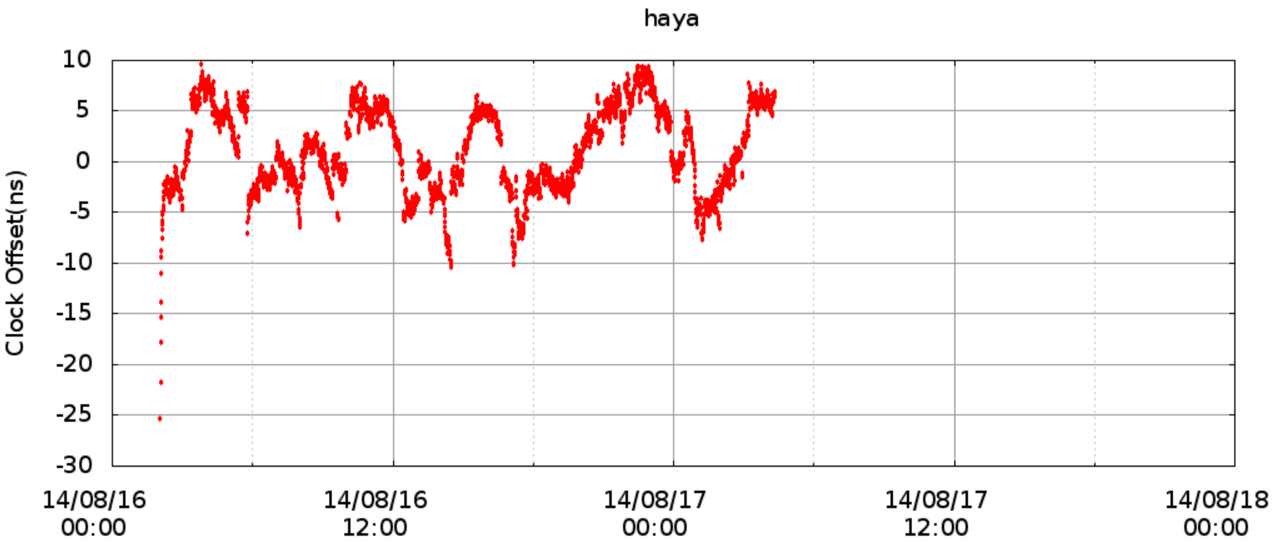


Table 8. Station Clocks

The following figures show the clock offset after the removal of a parabola.

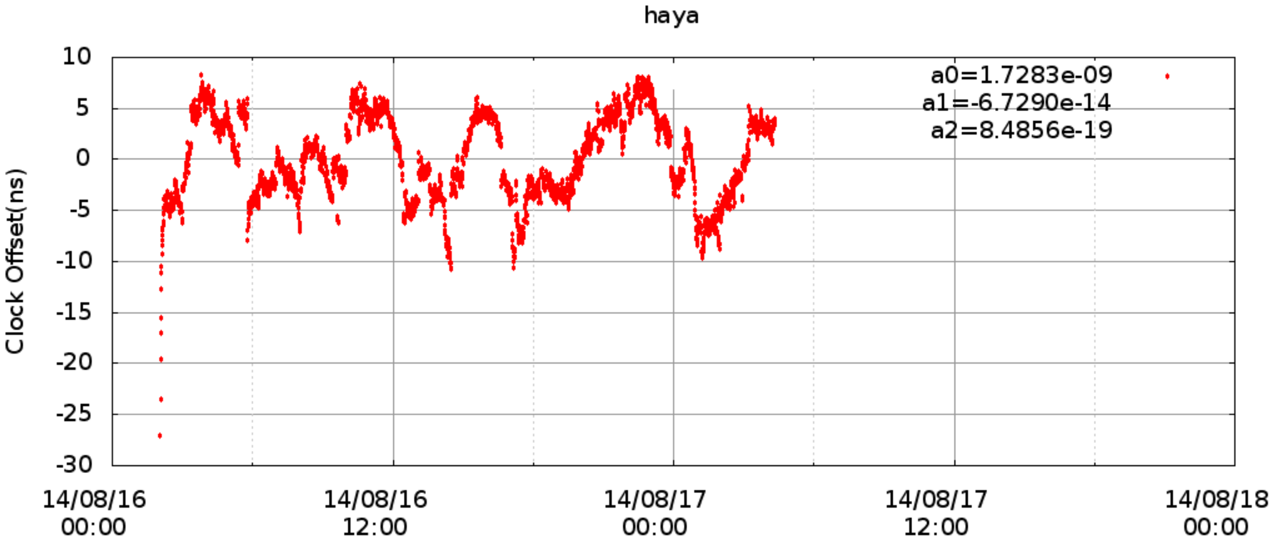
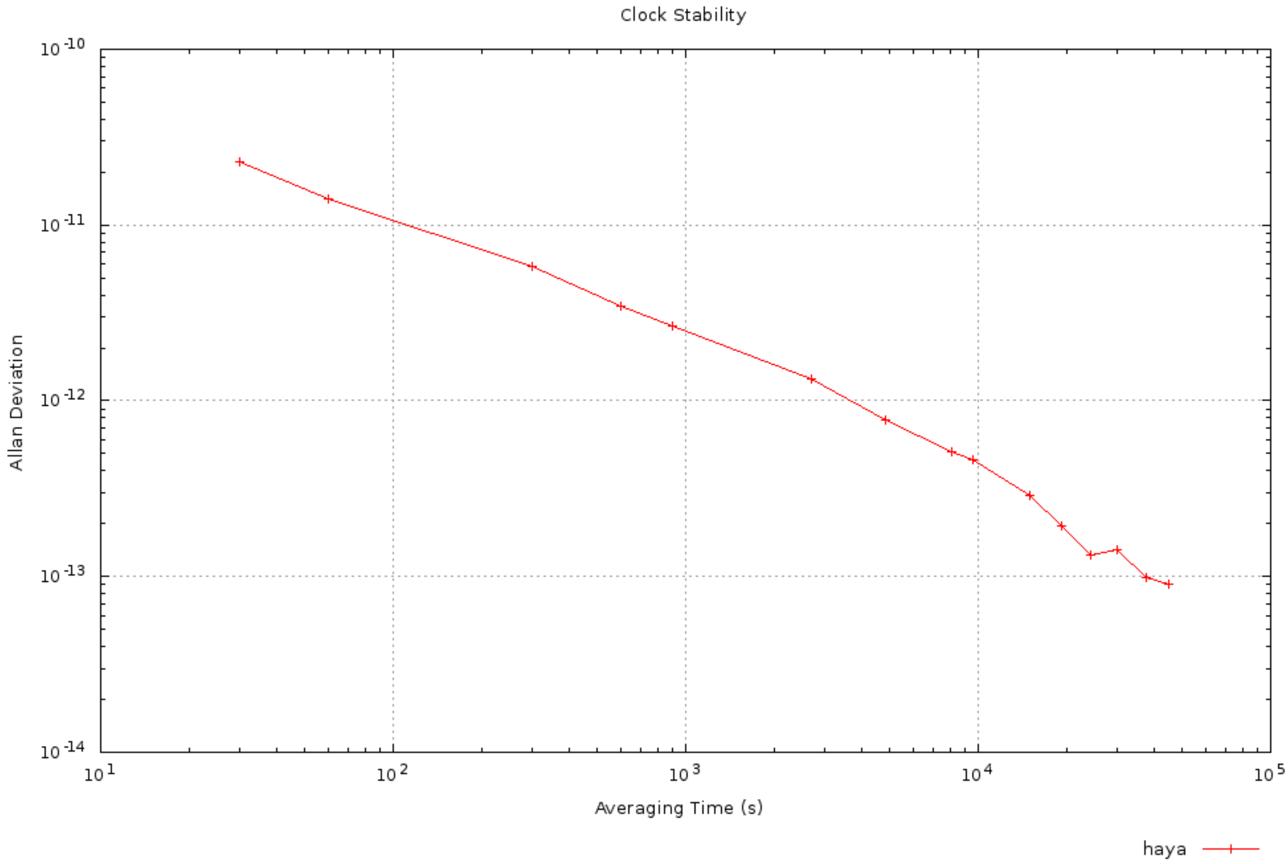


Table 9. Station Clocks



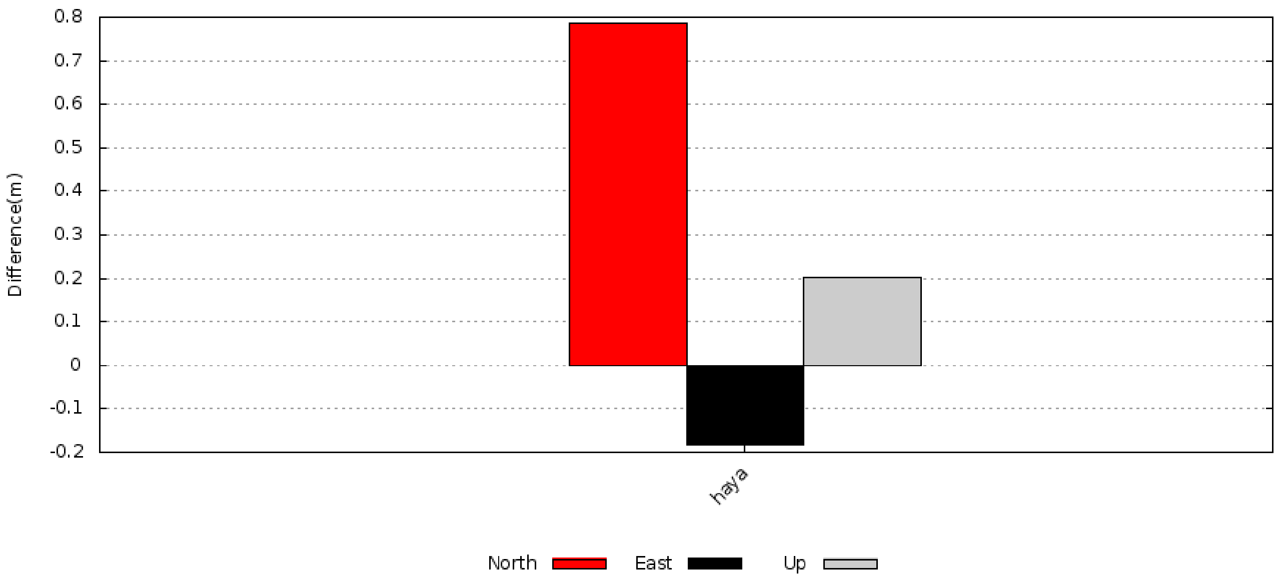
3.4. ESTIMATED COORDINATES

Station	Longitude(dms)	Latitude(dms)	Height(m)
haya (ETRS89)	153 35 58.3813	-28 40 37.4649	154.857
haya (ITRF08)	153 35 58.4024	-28 40 37.4809	154.869

Table 10. Estimated Coordinates

ETRS89 only applicable to Spain.

3.5. DIFFERENCE BETWEEN REFINED AND A PRIORI COORDINATES



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